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In the Name of God, the Compassionate, the Merciful

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Investigating the Challenges of Public Transportation and Users Behavior during and Post-COVID-19 Era

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ABSTRACT

The coronavirus (COVID-19) spread has significantly affected the city and its citizens from various aspects. Public transport systems are considered one of the essential parts affected by this virus to change citizens' travel behavior. The main aims of this study are, firstly, investigating the travel behavior of citizens in the period before, during, and after the coronavirus epidemic in the three metropolises in Iran (Tehran, Mashhad, and Isfahan) from four different perspectives. These four aspects include 1) the main reasons for the use of public transport in the pre-coronavirus era, 2) changes in the use of public transport during this epidemic disease, 3) the effect of the public transport system on the prevalence of COVID-19, and 4) behavioral changes in the use of public transport after the end of the epidemic. Secondly, assessing the impacts of these aspects on citizens' confidence in using public transportation after the coronavirus outbreak is based on the system dynamics model. The data collection tool is the Likert scale questionnaire, and the results were analyzed descriptively based on the evidence found.

Keywords

Public transportation, COVID-19, Challenges, Pandemic, System dynamics.

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1. Introduction

With the spread of COVID-19 disease, concerns about how to use public transportation during and in the post-COVID period have increased. On the other hand, one of the most critical concerns is the impact of public transportation on the prevalence of infectious diseases at the time of and after the spread of the disease. The COVID-19 pandemic has recently forced half of humanity to experience an unprecedentedly expansive lockdown. Naturally, this has brought urban transport systems to a near standstill, resulting in a sharp drop in carbon emissions and levels of air pollution in affected areas (Koehl, 2020).

The use of public transport holds many advantages over the use of a private automobile for the individual, the community, and the cities from the standpoint of such factors as energy conservation, environmental impact, social equity, and economy (Ojo, 2017). Promoting the use of public transport for urban mobility is not the only key to decarburization and mitigating climate change but also offers direct benefits for public health: improving air quality in densely populated areas, promoting active modes of transport, and encouraging activities that are less stressful than driving (Gutiérrez et al., 2020). While the huge negative effects of living through the COVID-19 pandemic are obvious – psychological stress, fear, severe global economic losses, overwhelmed healthcare systems, and general disruption of societies – the ongoing pandemic may also have some indirect positive impacts (El Zowalaty et al., 2020). By creating a smart structure, this paper explores the relationship between the answers provided by individuals to the questionnaire to identify and categorize the importance of criteria; As the importance of one criterion for the individual increases, what other criteria will be prioritized for this person.

This study uses the presented smart method to examine the internal relationship between the causes of using public transport in the period before the spread of coronavirus, how to change the behavior of citizens in using public transport during the spread of coronavirus, the impact of public transportation on the spread of COVID-19 disease, and how people change their behavior in using public transportation in the post-COVID-19 era from the perspective of citizens. As the largest metropolis in Iran and the Middle East, Tehran has been considered the case study in this study. More than 12 million population and gateway trips increase the floating population to more than 16 million people a day (Shirazian and Eskandari, 2021). Additionally, Iran, with 1,542,076 and 59,184 cases of confirmed infections and deaths persons, respectively, on February 17, 2021, is one of the high-risk areas from the spread of coronavirus perspective.

Therefore, the importance of studying the COVID-19 impacts on the public transportation system in the Tehran metropolitan is undeniable.

2. Literature review

The outbreak of the novel coronavirus disease of 2019/2020 (COVID-19) has resulted in still-increasing numbers of infections and deaths worldwide (Zhang, 2020). As of February 17, the total number of confirmed infections and deaths reached 72,385,935 and 1,615,052 persons, respectively, with the former still showing an upward trend. As a critical infrastructure component of cities, urban public transit offers a significant overall benefit to society (Fei, 2016), which is under threat by the growing COVID-19 disease. Many researchers and organizations have widely investigated the impacts of COVID-19 on the transport sector and corresponding measures (e.g., aviation (IATA, 2020; ICAO, 2020), maritime transport (McCauley et al., 2020; Teoh, 2020), railway (Citroen, 2020), and urban transport (EIT, 2020 a,b)).

In the context of urban transportation, Shen et al. (2020) tried to introduce the prevention and control measures for public transportation in China to promote the global response to COVID-19 and gathered important precautionary and control strategies relating to decreasing the COVID-19 spread in public transportation. Mogaji (2020) also analysed the present and long-term impact of COVID-19 on transportation in Lagos State, Nigeri, and noted a positive correlation between transportation affected by the pandemic and its effect on the people's economic, social, and religious activities. Gutiérrez et al., (2020) demonstrated the effects, challenges and research agenda associated with COVID-19 and urban public transport. Koehl (2020) also examined the possible consequences of COVID-19 on public health and used system thinking to evaluate how stimulus plans could maximize social, health and climate co-benefits. Abu-Rayash and Dincer (2020) proposed a model for smart transportation by considering COVID-19 impacts on the transportation sector and four indicators, including transport efficiency, technology integration, traffic congestion rate, and accessibility ratio. Their historical analyses of past health crises have indicated that the transportation sector will take a long time before full recovery and have shown substantial energy savings and GHG reductions associated with the pandemic. Zhang (2020) proposed a PASS (P: Prepare–Protect–Provide; A: Avoid–Adjust; S: Shift–Share; S: Substitute– Stop) approach for policymaking that accounts for COVID-19 and future public health threats in his study. This new approach has been designed to fill the gaps in transport policymaking amid pandemics by covering the significant aspects that should be addressed by governments, transport operators, transport users, and the public (Roozkhosh et al. 2022; Roozkhosh and Motahari Farimani, 2022).

As seen from the literature, there is a wide range of studies regarding urban transportation's current and future challenges during and after COVID-19. However, since this is a novel subject, it should be explored more accurately and from different aspects. This study examines the current behavior of the transportation system and the behavior of the system in the long run, and some key variables are examined by considering policies to improve the behavior of the transportation system in the long term.

3. Methodology

This study relied on a questionnaire to assess the current and leading challenges of public transportation during the spread of COVID-19 and in the post-COVID-19 era, which was distributed among the residents of three cities of Mashhad, Tehran and Isfahan via email, social media, and the professional network between 5 and 10 February 2021. For calculating the ideal sample size, the Cochrane formula was used. Based on the Cochrane formula, 384 questionnaires should be filled out regarding the case studies population.

384 questionnaires were collected with a response rate of 80%; Table 1 shows the demographic information related to the questionnaire. The analysis method of this study has been descriptive.

Table 1. Demographic information

	N=384	%
Gender		
Female	190	49.47
Male	194	50.52
City		
Tehran	209	54.42
Isfahan	71	18.48
Mashhad	104	27.08
Age Group		
15-25	175	45.57
26-35	172	44.79
36-45	21	5.46
46 above	16	4.16
Education Level		
Diploma	48	12.5
Bachelor	155	40.36
Master	158	41.14
PhD	23	5.98

The present study has investigated four different aspects, including the main reasons for using public transport in the pre- COVID-19 era, changes in the use of public transport during the epidemic, the effect of public transport fleet on the prevalence of the COVID-19, and behavioral changes in the use of public transportation in the post-COVID-19 era. All economic, social, environmental and health aspects were considered while developing the questionnaire questions. The effect of COVID-19 on public transport during the epidemic and in the post-COVID-19 era was investigated according to the data obtained from the questionnaire.

$$n = \frac{\frac{z^2pq}{d^2}}{1 + \frac{1}{N}\left(\frac{z^2pq}{d^2} - 1\right)} \tag{1}$$

Where n is the ideal sample number, N is the case studies population, d is the desired level of precision, p is the (estimated) proportion of the population that has the attribute in question, q is 1 – p. Z is the value of the normal variable with confidence level α-1.

System dynamics (SD) is a discipline and a methodology for the modeling, simulation, and control of complex, dynamic systems (Modares et al., 2021). The particular approach of SD lies in representing the issues or systems-in-focus as meshes of dosed feedback loops made up of stocks and flows in continuous time and subject to delays.

The dynamic system also tries to predict their long-term behavior in the future by examining the reference modes and past behavior of critical variables. On the other hand, by examining the challenges ahead with the help of questionnaire results, the rate of some exogenous variables used in the model can be found. In addition, after observing the system behavior, it is possible to change the value of some rates of exogenous variables based on policies and introduce their best rates in the long run. So that planners can rely on these rates to obtain the right policies and introduce the key system variables (Rajabi et al., 2022).

In this article, using the SD approach, the system behavior is considered for the 1000-day time horizon from February 17, 2021. Because the purpose is to review the system's behaviour and provide policy for the future. However, to check the model's validity, a 60-day interval is provided. And the citizens' confidence in using public transportation in the period before, during, and after the coronavirus outbreak is analyzed.

3.1. Case study

This study has examined the three metropolises of Iran, including Tehran, Mashhad and Isfahan. These three cities are among the largest cities in Iran, and public transportation is considered one of the most widely used commuting modes in all three cities. With a population of around 8.6 million (Statistics Center of Iran in 2016), Tehran is the most populous city of

Iran and the capital of this country. With a population of 3 million, Mashhad is the second-largest Iranian city and the religious capital of Iran. The latest statistical information reported by the Statistical Centre of Iran (SCI) in 2016 shows that the third most populous city of Iran is Isfahan, with a population of 2 million (as of 2016), which is one of the most industrial cities in Iran. Bus rapid transit (BRT) and subway lines are considered the most widely used commuting modes (public transport) in all three cities and one of the most important citizens' travel behaviors for daily trips. Public transportation in Iran has introduced new laws during the coronavirus epidemic, as in other countries, including personal hygiene, such as wearing a mask and observing social distancing[1]. However, the significant effects of this epidemic on reducing the daily use of public transport by citizens can't be ignored. The behavior of citizens in relation to public transportation before, during and after COVID-19 in three metropolises of Iran is discussed in the following.

4. The investigating of COVID-19 impacts on the public transportation

4.1. *Why were daily trips carried out by public transport before the COVID-19 pandemic?*

The results of the relevant studies and Table 2 show that 61.71.% (237 people) of the respondents agree that public transportation can be a money saver, and its low cost plays a significant role in prioritizing their commuting mode choice. Furthermore, 46.09% (177 people) of respondents believe that lack of access by personal vehicle, which directly affects the household economy, is considered the second most effective factor in choosing public transport as the commuting mode. As a result, the economic perspective has played the most important role from the interviewees' point of view in choosing a mode of transport to commute (use of public transportation) despite the concerns of urban planners in relation to the use of personal vehicles and relevant environmental problems, such as air pollution, noise pollution, greenhouse gas emissions, increase in respiratory diseases, only 35.67% and 40.62% of respondents (questions 8 and 9 are related to environmental issues and urban air pollution), believe that environmental issues play an important role in choosing public transport as commuting mode. It means that citizens do not pay enough attention to environmental concerns when choosing a mode of transport to commute. Finally, from the interviewees' point of view,

[1] Social distancing, also called “physical distancing,” means keeping a safe space between yourself and other people who are not from your household. To practice social or physical distancing, stay at least 6 feet (about 2 arms' length) from other people who are not from your household in both indoor and outdoor spaces.

the two issues of the possibilities of walking to a public transport station (proper access) and the convenience of public transport had the least effect on the choice of public transport before COVID-19. When using public transport, people face insufficient public transport stations in metropolitan cities of Iran and poor quality (high congestion, poor seats, noise, etc.). On the other hand, although reducing travel time for passengers is considered one of the most important goals of public transport design, 42.44% (163 people) of the interviewees did not consider travel time reduction as an essential factor in public transport mode choice, which can indicate improper timing and efficiency of the public transportation system in metropolitan areas of Iran.

Table 2. The main reasons why daily trips were carried out by public transport before the COVID-19 pandemic

The main reasons why daily trips were carried out by public transport before the COVID-19 pandemic	**Completely agree**	**Agree**	**Medium**	**Disagree**	**Completely disagree**	**Average Likert scale**
Lower costs	127	110	96	32	14	3.76
Lack of access to personal vehicle	96	81	108	69	26	3.39
More convenience when using public transport	42	66	113	110	47	2.85
Lack of access to parking at the destination	52	82	107	102	38	3.01
Less travel time	51	83	82	104	59	2.89
High traffic and fatigue from driving a personal car	56	88	105	87	43	3.06
Ability to walk more (from home to the station) when using public transport	37	69	108	122	43	2.83
Protecting the urban environment and reducing fossil fuel consumption	71	66	135	81	29	3.12
Prevent air pollution in the city	53	103	123	81	22	3.21
Existence of compulsion and impossibility of using a personal car due to traffic restriction plans	47	112	102	81	39	3.12

4.2. *What has changed with the outbreak of coronavirus in the way you use public transportation?*

As the results of relevant studies and Table 3 show, people often avoid unnecessary travel to protect their health and the health of those around them in the COVID-19 era and turn to Internet software and online shopping for more weekly and daily shopping than ever before. On the other hand, according to the view of 65.10% (250 people) of the interviewees, they did not use public transportation such as subway or city taxis at all in the COVID-19 era and preferred to use Internet taxis and agencies; this issue is important from various aspects, which will be discussed in the next sections. Many environmental and economic problems will be created due to less use of public transport and the preference to use Internet taxis or agencies.

For example, some of the most important environmental and economic problems include the increase in emissions of greenhouse gases (GHG) due to a large number of taxis in the city, the increased cost of internet taxis, the effect of costs in the market basket, increased air pollution, increased respiratory diseases and other cases. From the interviewees' point of view, lower cost and air pollution, which were among the main factors in public transportation choice instead of personal transportation in the pre-corona era, have changed significantly during the epidemic, which will be associated with irreparable economic and environmental pressures. According to the investigation results of questions 6 and 7 of Section 2, which were related to the coercion and authority of individuals to use public transport in the COVID-19 era, both coercion and authority have minimal effect on individuals' decisions to use public transportation. People have a minimal inclination to use public transportation during the corona due to the fear of being indoors and not observing social distances. People were very reluctant to use public transportation during the COVID due to fear of being indoors and disregarding social distancing. However, the number of people forced to use public transportation due to economic and time constraints is more than those who want to use it in this era.

On the other hand, according to the results, people are inclined to reach their destinations via cycling and walking. This may be due to the World Health Organization's recommendations that the coronavirus remains "viable in aerosols" — infectious in the air — or due to the incorrect placement of public transport stations in the city. This will be associated with many environmental and health problems that lead to increased greenhouse gas emissions and air pollution, leading to the spread of diseases such as obesity, diabetes, and high blood pressure in people due to reduced mobility.

Table 3. Changes in the way people use public transportation during the COVID-19 pandemic

Changes in the way people use public transportation during the COVID-19 pandemic	**Completely agree**	**Agree**	**Medium**	**Disagree**	**Completely Disagree**	**Average Likert scale**
I completely eliminated unnecessary trips	231	83	49	13	4	4.37
I do not use public transportation (bus and subway) in any way.	193	57	63	39	28	3.90
I do not use public taxis in any way	133	73	98	48	28	3.61
I use the Internet and personal taxis instead of public transportation.	120	100	91	46	23	3.65
I use the Internet more than in the past to buy and receive services	148	112	87	26	10	3.94
I continue to use public transportation as before due to coercion and restrictions.	27	27	64	120	140	2.16
By my own choice, I continue to use public transport as before.	11	22	46	138	162	1.90
I mostly use walking and cycling to reach my destination	41	61	100	87	91	2.26
I use public transportation more than personal vehicles to get to my destination	39	41	41	79	168	2.19

4.3. *What do you think about the effect of public transport on the onset of COVID-19?*

Based on Table 4, the majority of respondents, 74.73% (287 people), believed that the prevalence of COVID-19 in public transport is unavoidable, and 65.10% (250 people) of them considered public transport as one of the most dangerous places for the spread of the virus. Also, in their view, only personal hygiene (wearing a mask, gloves, and frequent use of disinfectants) when using public transportation is not enough to avoid illness, although necessary. It is necessary to create a coordinated campaign among all people involved in public transportation, this coordination does not end with the compulsion to wear masks all people, and there is a need for frequent disinfection of transportation devices and, most importantly, the reduction of congestion, the observance of social distance and appropriate timing in the use of public transport. According to the results of studies, people only decide to use public transportation if they are sure that public transportation is always hygienically disinfected and the whole people involved observe their health and respect the social distancing.

Table 4. The effect of public transport fleet on the prevalence of COVID-19

What is your opinion about the effect of public transport fleets on the prevalence of COVID-19	Completely agree	Agree	Medium	Disagree	Completely Disagree	Average Likert scale
1. The use of public transportation is the main reason for increasing the outbreak of COVID-19 in metropolitan areas	108	142	102	26	4	3.85
2. Transmission of the disease in public transport is inevitable	158	129	59	23	12	3.93
3. The use of public transport does not affect the risk of contracting the disease	7	4	13	132	226	1.52
4. If personal hygiene is observed, people will not get sick while using public transportation possibility.	13	61	132	120	53	2.63
5. By disinfecting the environment of public transport, the transmission of the disease in public transport can be controlled.	33	58	165	79	43	2.89
6. By reducing congestion and proper timing of using public transportation, disease transmission can be controlled.	53	120	157	33	18	3.40
7. Citizens' commitment to using masks and personal hygiene is the most important factor in reducing transmissibility in public vehicles.	99	127	122	21	13	3.72

4.4. *How will you use public transport in the Post-COVID-19 Pandemic era?*

According to Table 5, although 58.85% (226 people) of the interviewees admitted to using it without worries after the COVID-19 outbreak, 64.32% (247) of the interviewees believed that they would use public transportation with more caution than health tips and prefer to use masks and continue to disinfect public vehicles in the Post-COVID-19 Pandemic era. However, one of the most important effects of this virus on citizens' travel behavior is walking and cycling. Most respondents believed they would continue their habit of walking and cycling in the Post-COVID-19 Pandemic era, which plays a vital role in cities and citizens in various economic, social, and environmental aspects. On the other hand, the use of the Internet in daily activities such as shopping, payments, and other things that most citizens have tried to use during the COVID-19 era also plays a significant role in doing citizens' affairs in the post- COVID-19 era. In other words, most respondents (with a rate of 3.14) claimed they would avoid unnecessary travel and use the Internet as much as possible for daily activities in the post- COVID-19 era. This will reduce the economic benefits (in terms of travel costs, fuel costs, etc.) for individuals and help to reduce greenhouse gas emissions. However, most interviewees claimed that they would use public transport more cautiously (after discovering the COVID-19 vaccine and in the post- COVID-19 era, but 29.42% (113 people) still claim to continue to use their vehicle to reach their destinations in the post- COVID-19 era. It is crucial to pay attention to this issue, given that public transportation is considered one of the essential commuting modes to achieve sustainable development goals. So, city planners and managers must put policies on their agenda to increase safety and regain people's confidence to use public transportation in the post-COVID-19 era.

Table 5. How people use public transportation in the post- COVID-19 era

How will you use public transportation after the epidemic?	Completely agree	Agree	Medium	Disagree	Completely Disagree	Average Likert scale
Despite the end of the pandemic, I will still keep the use of public transportation limited.	34	61	97	144	44	2.72
After the end of the COVID-19 pandemic, I will still use my personal vehicle to get around the city.	34	79	119	110	38	2.89
I will eliminate unnecessary trips and use the Internet more than in the past to buy and receive services	44	96	134	84	22	3.14
I will use public transportation safely in the post-COVID-19 era.	96	130	105	33	16	3.67
I will continue using public transportation more cautiously in observing health tips in the post-COVID-19 era.	100	147	96	24	13	3.77
I will maintain the habit of walking and cycling.	78	114	127	44	16	3.50

5. Results

5.1. *Presenting a dynamic hypothesis and causal loop diagrams*

The causal loop diagram shows the relationships between the variables drawn by the dynamic hypotheses. For example, with the increase in travel, the disease spreads among more people, so the number of patients increases, the fear of disease is expected to increase, and the greater the fear, the less public transportation is used. On the other hand, with the increase in the number of patients, people increase the use of personal vehicles to maintain their health. With the increase in traffic with private vehicles, traffic and air pollution increase, and as a result, people again want to use public transportation. As the number of people using public transportation decreases (such as subways, buses, etc.), the crowd will decrease, eventually reducing the number of patients. As observed, increasing one factor in the cycle reduced the same factor, so the loop is a balancing type. Figure 1 shows all the loops.

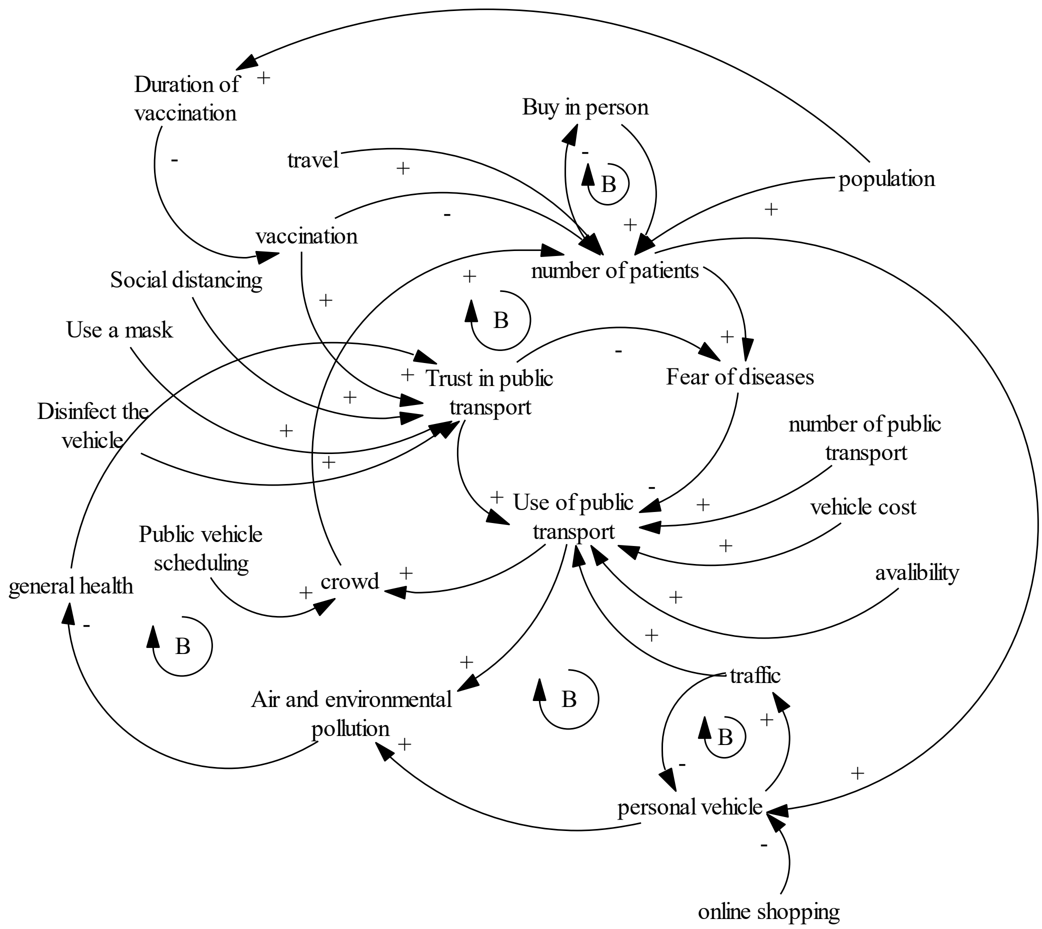

Figure 1. Causal loop diagram of model

5.2. *The stock and flow charts*

Table 6 shows some of the most important formulas of stock and flow variables. These formulas have been formulated for the 1000-day horizon to consider the impact of coronavirus on public transportation in the three cities of Tehran, Mashhad, and Isfahan. The relationship between endogenous, exogenous, auxiliary, accumulation, and flow variables has been investigated.

Table 6. Model formulation to evaluate the impact of coronavirus on transport

Initial value "per day" (unit)	Variable/ parameter type	Formula	Variable
5000000 (number)	stock variable	Integral (number of people using public transportation + number of using public transportation again-using change rate)	total number of people using public transportation
20000 (number)	stock variable	Integral (using change rate-number of using public transportation again)	total number of personal vehicles, and so on
190000 (number)	stock variable	Integral (number of improved)	total number of improved
262153 (number)	stock variable	Integral (number of patients-number of death-number of improved)	Total number of patients
13000000 (number)	stock variable	Integral (birth-death-number of patients)	Papulation
100000 (number)	stock variable	Integral (number of death)	total number of deaths
(Number)	Flow variable	papulation*rate of birth	birth
(Number)	Flow variable	DELAY1(crowd*number of patients rate*papulation, 10)	number of patients
(Number)	Flow variable	probability of death*Total number of patients	number of deaths
	Auxiliary variable	total number of improved/papulation	The ratio of improvements to patients
	Auxiliary variable	The ratio of improvements to patients*total number of patient rate	the effective number of patient rate
	Flow variable	DELAY1(rate of personal vehicle*Total number of patients, 10)	using change rate
(Number)	Auxiliary variable	(Effective crowd rate "Effective in-person purchase rate "+Effective travel rate +online shopping Public vehicle scheduling) *total number of people using public transportation	crowd
	Auxiliary variable	general health*Social distancing*Use a mask	Trust in public transport
(Number)	Flow variable	DELAY1(Disinfect the vehicle * Fear of diseases * rate of public transport users * traffic rate*total number of personal vehicle and so on, 10)	number of using public transportation again
(Number)	Flow variable	DELAY1(effective number of patient rate*rate of Improved number, 10)	number of improved

The formulation given in Table 6 is related to the accumulation, flow, and endogenous auxiliary variables, the rate variables are part of the exogenous variables, and their values are extracted from the questionnaire (the Average Likert scale column of Tables 2-3-4-5).

To formulate and use the dynamic conditions between the variables, simulation in the Vensim environment has been done, which first is drawn the accumulation-flow diagram according to Figure 2. Flow variables represent stock variables' input and output values, and auxiliary variables (internal and external) help to complete loops and relationships between variables. The following diagram shows the stock and flow diagram of the model, which examines the model relationships.

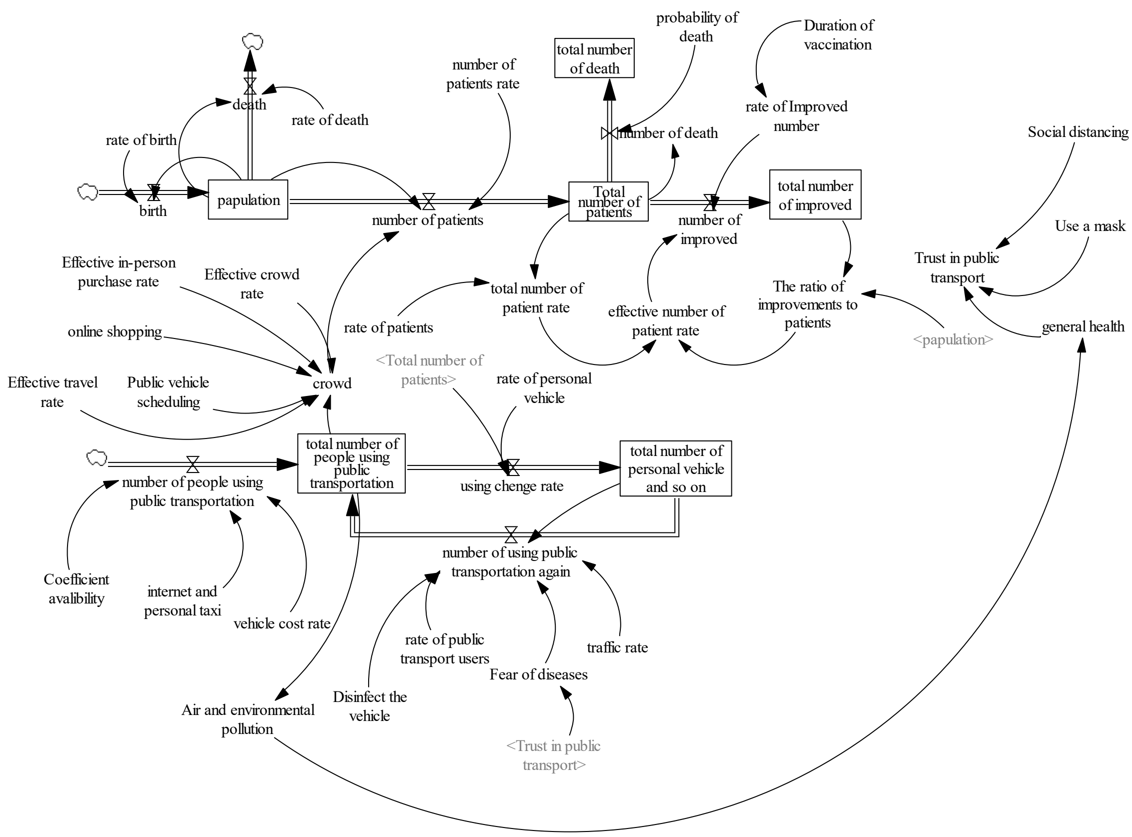

Figure 2. Stock and flow diagrams to evaluate the impact of coronavirus on public transport

5.3. *The numerical simulation results*

The following diagrams show the behavior of model mode variables after numerical simulation. Figure 4 shows the results of all simulation mode variables. The simulation horizon is intended for 1000 days from the beginning of February 2021. The chart below (Figure 3) shows the exact statistics of COVID-19 patients in Iran since February 2021, which can be used to check the model's validity with the total number of patients obtained from the model simulation.

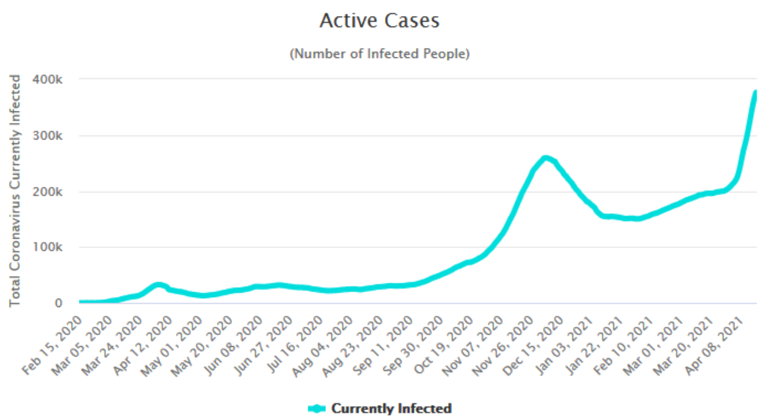

Figure 3. The exact statistics of COVID-19 patients in Iran since February 2021
(Source: www.worldometers.info/coronavirus/country/iran/)

Based on Figure 3 and considering February 2021 as the starting point, the system's behaviour is exponential. The number of patients is increasing, and now comparing it with the pattern obtained from the model shown in Figure 4, It can be understood that the model has a good reputation because the model behavior in the real world has grown exponentially during that period.

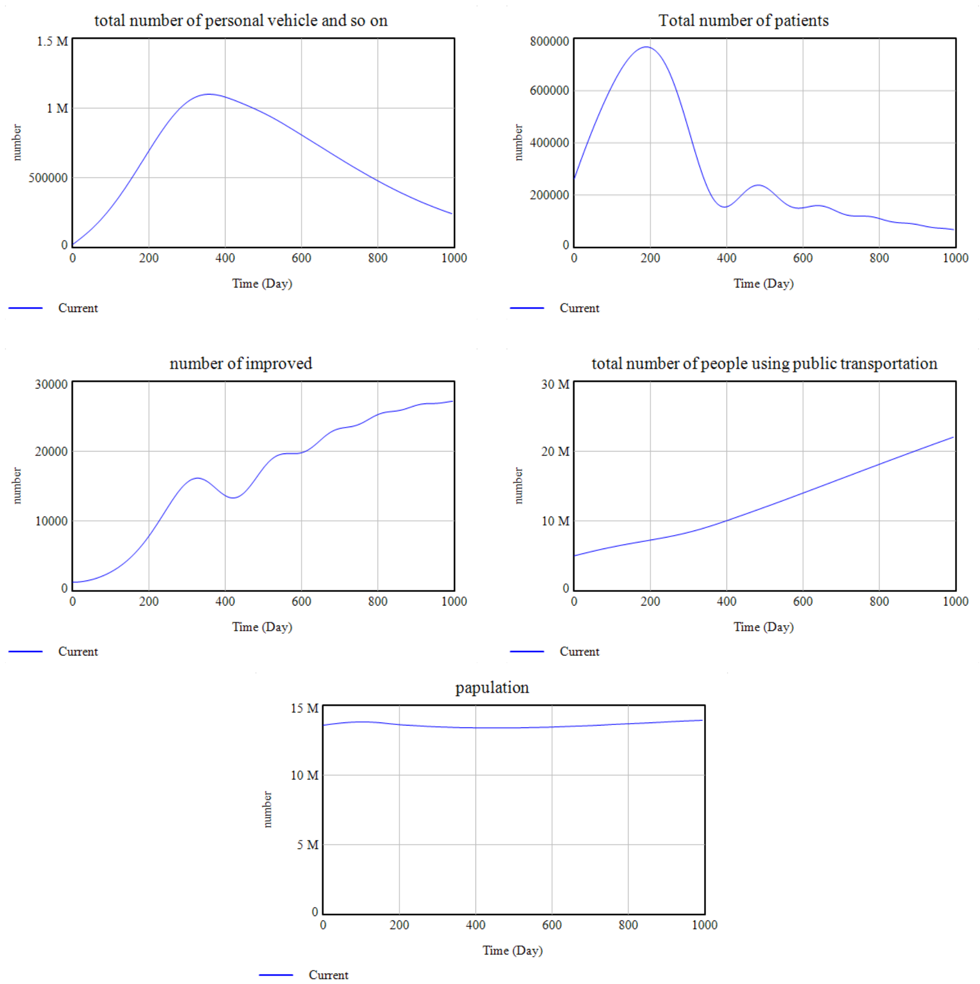

Figure 4. Simulation results of model variables

5.4. *The model validation*

After drawing and formulating the accumulation-flow diagram, to ensure the accuracy and precision of the model, it is necessary to test the model. In this research, three tests have been performed to validate the model. According to the reported coronavirus statistics related to Iran, the real behavior of the variables has been extracted from a valid website.

5.4.1. Test the ability of the model under limited conditions

In this test, other relevant variables are expected to behave correctly by zeroing or multiplying the coefficient of one variable. Therefore, in this model, the disinfection and public transport hygiene rates were considered zero, and the results were reported in Figure 5.

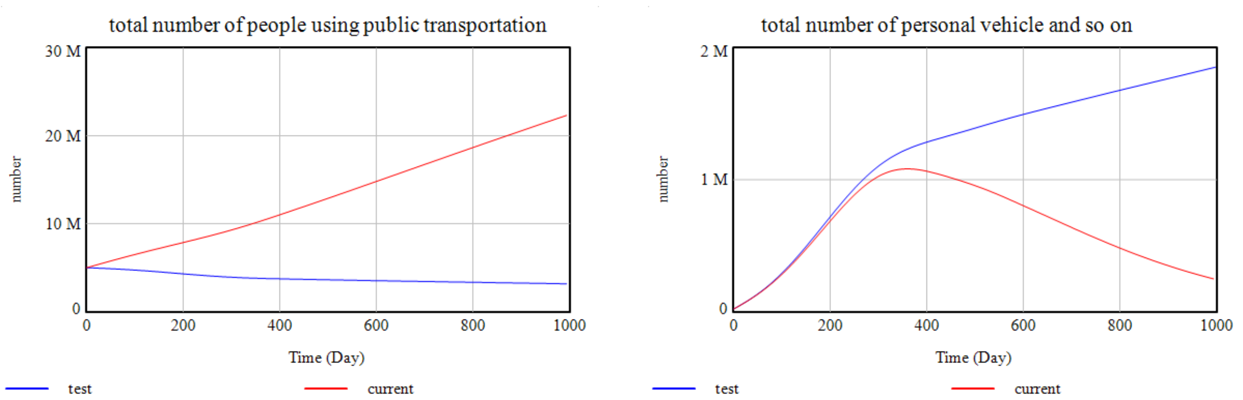

Figure 5. Reset to zero disinfection rate and study its effects

Figure 5 shows that if the rate of disinfection and hygiene of public transport is considered zero, then the use of public transport will decrease, and the use of personal transport will increase sharply; Naturally, in these circumstances, users will prefer to use their personal vehicles for their own safety.

5.4.2. Sensitivity analysis test

This test shows that if the coefficient of one variable changes slightly, the behavior of the other variables should not change sharply. To prove this test, in the model, the travel coefficient changed from 0.0001 to 0.0002, but no significant change was observed in the trend of the graphs. Figure 6.

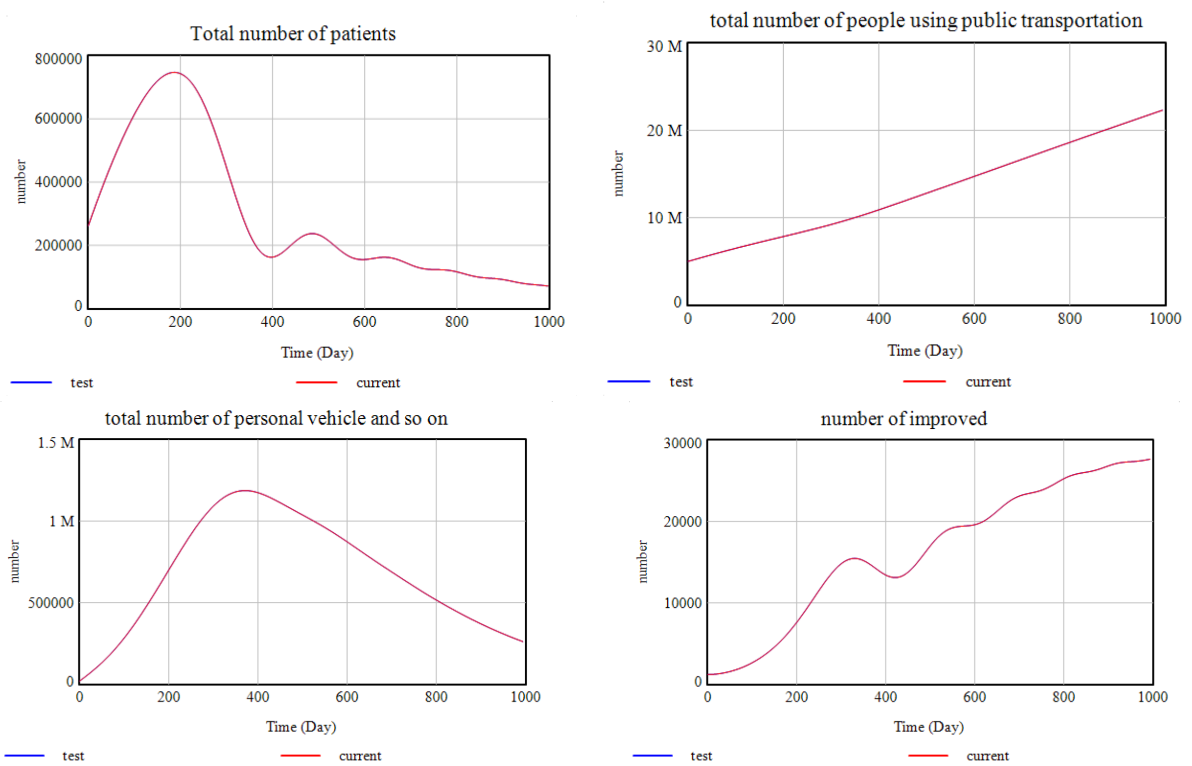

Figure 6. Sensitivity analysis test charts

The conformity of the diagrams in Figure 6 shows the accuracy and validity of the proposed model. Because with small changes, no special change is expected in the model process.

5.4.3. Dimension test

This test involves a Dimension analysis of rate equations. This test was confirmed based on the compliance of all units with the option of unit check-in Vensim software.

5.5. *The policy design and evaluation*

One of the most important capabilities of the systems dynamics approach is to consider different policies and compare the results of these policies. In these policies, according to the nature of the problem, different decisions are made, and according to the results, different policies can be evaluated, and the results can be compared with each other. In this issue, the effect of social distance on the variables of problem stock was investigated.

5.5.1. The policy of social distancing

This section examines the effect of changing social distance on public transport and other variables. One way to reduce the number of patients is to increase social distancing. Table 7 shows the relevant policy. The relevant results are also shown in Figure 7.

Table 7. The policy of social distancing

Policy	Decision Variable	Value
First	social distancing	0.001
Second	social distancing	0.01
Third	social distancing	0.1

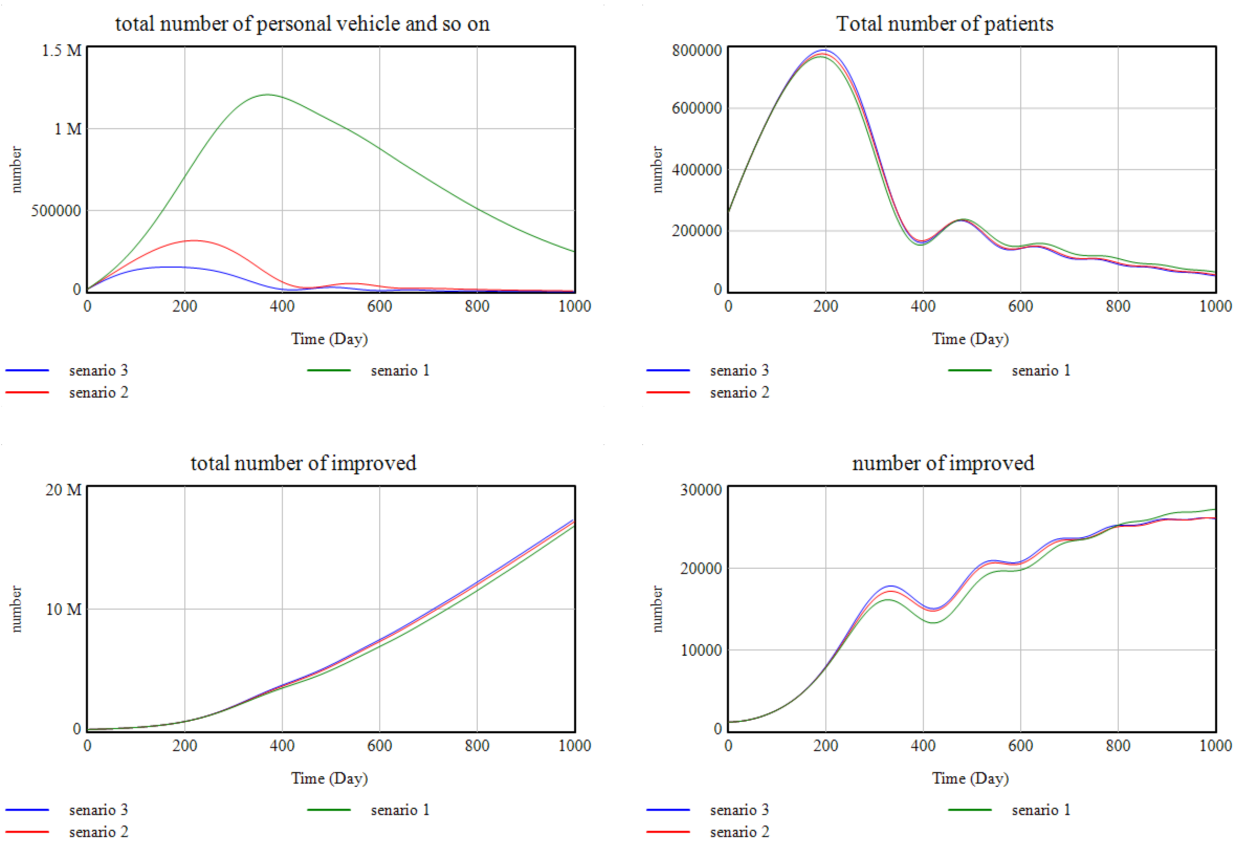

Figure 7. Social distancing policies

As can be seen, the higher rate of social distancing and the lower use of public transportation due to the reduction of congestion, and this decrease have also positively affected the rate of patients. On the other hand, if the social distance rate is more than 0.1, the personal vehicle volume will increase a lot, which will cause environmental pollution, etc., so in this model, the best rate used is 0.01.

6. Conclusion

Despite the many economic, environmental, and social problems created by COVID-19 on public transportation, including the preference to use more personal vehicles, spending more money on internet taxis and agencies, wearing masks, gloves and the constant use of disinfectants, fear of being in closed public spaces such as the subway and buses and other items, more studies probably would prove that COVID-19 has had many benefits. These include more use of internet services and providing the proper context for moving to the smart city, increasing walking and cycling, reducing air pollution and greenhouse gas emissions, paying more attention to health issues, etc.

According to the results of this study, in the three metropolises of Iran (Tehran, Mashhad, and Isfahan), although the majority of respondents used public transportation for daily commuting before the outbreak of the virus due to economic purposes such as lower costs of public transport (61.71%) and no access to a personal car (46.09%), 65.10% of the interviewees claimed that they did not use public transport at all during the epidemic and preferred to use Internet taxis or agencies (57.29%), to protect their health, that is the economic pressure on households and the environmental problems caused by the release of fossil gases during the COVID-19 epidemic due to the use of single-passenger taxis. On the other hand, 74.73% of the respondents stated that it is impossible to avoid illness on public transport, which can be considered the most important reason people do not use public transport. Respondents believed that they would continue to use public transportation with more caution in the post- COVID-19 era, which requires the maximum attention of policymakers and city managers in the field of public transport in the post- COVID-19 era. Some effective factors in the use of public transport in the post-COVID-19 period include making wearing masks in indoor public spaces mandatory in the post-COVID-19 era, the continuation of disinfection of transport equipment, and proper use schedule from public transportation to social distancing. Additionally, based on the system dynamics approach, the variables affecting transportation according to the existing conditions in the pandemic situation were examined, and the change in the behavior of overcrowding of public transportation in the three cities of Tehran, Mashhad, and Isfahan in Iran was identified. The horizon studied in this research is 1000 days and is considered from February 17 2021. Also, considering a scenario, the effect of social distance on the status of using public transportation in pandemic conditions has been investigated. The results indicate that after a while, with the decrease in the epidemic peaks of COVID-19, public transportation will increase, and personal transportation traffic will decrease. However, in the current situation, people prefer private cars over public transport.

Disclosure statement

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

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The Nature of Hard and Soft Problems and Their Problem-Solving Perspectives

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ABSTRACT

Problem-solving requires adopting an appropriate approach that is influenced by understanding the nature of problems ranging from soft to hard. Research results indicate that there is still a lack of an accurate understanding of the nature of problems while researchers are engaged in adopting an approach to addressing the problems. Therefore, this research seeks to investigate the nature of hard and soft problems and the quality of their resulting solutions. This research endeavors to examine the nature of soft and hard problems. It is believed that identifying the attributes of different types of problems helps strike a balance between the nature of the problem, the problem-solving method, and the methodology used. Therefore, this research has addressed the nature of hard and soft problems and their perspectives on solving problems to fill gaps left in systems thinking studies. Also, current research helps researchers set a balance between attributes of the problem and ways of thinking about it, better identify the nature of the problem and better adapt the methodology to the problem. Based on the results of this research, soft problems are influenced by the context of the problem. In addition, in hard problems, the structure of the solution is determined by the problem structure. In contrast, in soft problems, the structure of the solution demands a proper understanding of the logical and cultural phenomena of the problem context. That is why the quality of the answer to hard problems is a normative, right, and definitive solution, while the answer to soft problems is a procedure composed of concepts and meanings. The findings of this study suggest that, like a soft problem, the solution to a soft problem is a social reality that all interested groups collectively enact. Consequently, the solution is a system of concepts that all the interested groups accept, and over its implementation, there is a shared understanding among all the interested groups.

Keywords

Soft problems, Soft systems methodology, Phenomenology, Interpretivist approaches, Soft OR.

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1. Introduction

The problem acts as an impediment to achieving the objective or purpose. Jonassen (2000) considers the problem an unknown entity in a situation that creates value for the problem solver if he/she can find such an unknown entity. In Jonassen's (2000) view, problems are defined in 3 distinctive dimensions. 1- Structuredness 2- Complexity 3- Abstractness. Structuredness refers to the relationship between problem attributes and the surrounding parameters of the problem (Jonassen, 1997, 2000). These parameters can constitute problem attributes, the diversity of relationships between problem components, and how a problem is defined. Structuredness is more related to the availability of information and contextual richness.

Complexity is associated with the number of problem attributes and the degree of connectivity among these attributes. If there is a surge in the number of these attributes, the problem becomes more complex. Abstractness (domain specificity) is also related to the generic nature of the problem and its universal characteristics. If the degree of abstractness of a problem is low, problem-solving activities are more situated. The interaction of these three dimensions plots the problems on a continuum of hard to soft. Hard problems are structured, typically simple, and less complex, and their continuum is generic and abstract. Some research has referred to the situation of these problems as a puzzle. Thus, in this manuscript, hard problems are considered equivalent to puzzles (Jonassen, 1997, 2000; Pidd, 2003; Revans, 2011; Segal, 2004), structured problems (Voss, 1988), or tamed problems (Conklin, 2005; Rittel and Webber, 1973). The abstractness of this set of problems facilitates the definition of these problems; moreover, the root cause of the problem is known to us or can be easily uncovered. This set embraces context-free problems in which the stopping point of the answer is evident (Rittel and Webber, 1973), and there is general agreement on the success of finding a solution to the problem (Conklin, 2005). Therefore, such a set of problems have one single best solution. Further, it is also possible to solve them by recruiting programmed knowledge. Knowledge was extracted from solutions that followed an orderly and linear 'top-down' process, working from the problem to the solution. In hard problems, the criteria for evaluating the solution are well-defined and can be determined as either correct or incorrect.

Soft problems are the opposite of hard problems. This set of problems is unstructured, have a complex nature, and is tied to the context. In this paper, soft problems are perceived as equivalent to messes (Ackoff, 1974; Novick and Bassok, 2005), ill-structured problems (Simon, 1973; Voss, 1988, 2014), ill-defined problems (Chi et al., 2014; Eastman, 1969; Reitman, 1964) or wicked problems (Churchman, 1967; Conklin, 2005). The complexity of these problems has inspired researchers to examine the nature of these problems in various respects. Different researchers have addressed soft problems from a wide variety of perspectives, for example, from an information processing perspective (Newell and Simon, 1972), from the planning and policy-making perspective (Rittel and Webber, 1973), from a management systems perspective (Checkland, 1994) and also from a psychological perspective (D'Zurilla and Nezu, 1999; Kitchner, 1983; Mayer, 1992; Voss, 1988, 2005; Voss et al., 1983).

It is noteworthy that researchers have a consensus that it is not easy to define soft problems and explore the boundaries, variables, and objectives of these problems. Therefore, numerous and sometimes contradictory definitions of a soft problem are available among problem solvers. On top of the fact that there are no identical interpretations of the definition of the problem, the methods for finding the solution to soft problems are not straightforward. In such cases, as Simon (1959) points out, as a consequence of human cognitive capacity limitations, decision-makers and problem solvers would rather have solutions that are not necessarily rationally optimal but are considered satisfactory. Therefore, in this set of problems, the criterion for finding the answer is not lucid enough, and the problem solvers are usually pleased with satisfactory solutions (Simon, 1976). Since the problem-solving in this set of problems departs from the rational approaches and turns into a cognitive one; therefore, the criteria for evaluating the results of this set of problems are tied to values, beliefs, faiths, behaviors, and contradictory certitudes. Accordingly, instead of the quest for right or wrong answers, evaluation is carried out by considering better, worse, or somewhat good criteria (Edmonstone, 2014). Furthermore, soft problems are characterized as the creators of other soft problems because an attempt to solve one aspect of soft problems can create and reveal other soft problems (Rittel and Webber, 1973).

It is worth mentioning that given the importance of soft problems in social sciences and management, identifying their dimensions can promote a better understanding of these problems and, consequently, have a significant impact on solving them. Creswell and Clark (2007) articulate that the researchers' philosophical assumptions influence research studies. Hence, it can be contended that if the researcher is not fully aware of the nature of a problem and its philosophical assumptions, (s)he might mistakenly recruit methods and methodologies in solving and confronting the problem. Therefore, it is paramount to understand the differences between different types of problems because the nature of the problem helps the researcher define the problem, pick out the appropriate approach to address the problem, and set up the research process. This issue is of high significance, in particular, in soft problems, because the misperceptions and misunderstandings observed in the secondary literature on the nature of these problems demonstrate that appropriate methodologies for addressing these problems have not been applied (Checkland and Poulter, 2006; Hanafizadeh and Mehrabioun, 2017; Holwell, 2000). With that in mind, the first question can be formulated as follows.

1. What is the difference between the nature of soft and hard problems?

For this reason, this research examines the nature of soft and hard problems. It is believed that identifying the attributes of different types of problems helps strike a balance between the nature of the problem, the problem-solving method, and the methodology used. It can also narrow down the disparity and incommensurability between methodology and the nature of the problem. In some cases, the problem under study may not be hard; thus, the researcher's use of hard problems' problem-solving approaches premised on abstraction has confounded the nature of the problem and posed a new problem rather than solved the problem.

On the other hand, it is essential to discretely investigate the difference in the quality of solutions for hard and soft problems. Such an investigation leads to researchers' expectations of the solutions being properly articulated, and their aim of problem-solving is precisely defined. The question that may arise is the difference between the results of solutions for hard and soft problems. Can we expect the same answers? If different results are accumulated, which of them is correct? Therefore, an account of the difference in the quality of solutions for hard and soft problems merits further investigation. Therefore, the second question of this research is:

2. What is the difference between the quality of solutions in hard and soft problems?

This research is organized into six sections. The second section examines the nature of hard and soft problems. The third section responds to the second question of the research and seeks to examine the difference in the quality of solutions to hard and soft problems. The fourth section summarises the differences between soft and hard problems. Discussion is presented in fifth section. Finally, the conclusion and implications are discussed.

2. Hard problems

Hard problems are entirely structured and for which there is a definitive optimal solution. Hence, there are common and consistent interpretations of the solutions to this set of problems, and applying mathematical and statistical methods to solving these problems is commonplace (Pidd, 2003). According to Jonassen (2000), the structuredness of hard problems makes both the initial and desired states of problem-solving and the problem-solving procedures well-known and well-defined. Another attribute of hard problems is their simplicity and abstractness. This simplicity stems from the sustainability of the components of the problem over time, which prompts the problem-solving process to confront a less cognitive operation on behalf of the problem solver (Frensch and Funke, 2014).

On the other hand, these problems are less contingent on the problem situation and require generalizable problem-solving skills such as economic analysis; consequently, they are less subjective and more objective (Jonassen, 2000). In hard problems, both the problem and its domain are definitive; there is also a general agreement on how success in problem-solving is determined (Conklin, 2005; Edmonstone, 2014). In this set of problems, those irrational behaviors and actions cannot be traced to humans in the event of uncertainty. Still, uncertainty is brought about by the inaccuracy of measurement tools and disruption in the problem's parameters. Information from uncertain parameters can be considered probable, stochastic, or even fuzzy. In hard problems, the problem solver is a rational individual with good judgment in setting parameters, prioritizing, weighing options and alternatives, and solving a problem. Hard problems are not necessarily simple problems. The diversity and multiplicity of its components can make the hard problem complicated. However, there is an existing knowledge base of tried and tested solutions to hard problems; further, there are solutions to such complicated problems. The solution to such problems follows an orderly and linear top-down process.

In hard problems, even if the dimensions of the problem are large, usually by adopting reductionism approaches, the researcher attempts to break down the big problem into smaller ones (see Figure 1). In the process of decomposing the big problem into sub-problems, the decomposition continues as long as the best solution can be employed for a sub-problem. Therefore, there is one best solution in the hard problem situation, corresponding to each of the smaller sub-problems. Hence, the answer derived from solving sub-problems has the desirable quality and can be used in the problem situation. The complexities that researchers encounter in dealing with hard problems involve 1) Understanding the structure of the main problem and structuring the sub-problems during the process of decomposing the main problem into sub-problems; 2) Assigning a single best solution to each of the sub-problems to solve them or developing an instruction/procedure for solving a sub-problem; and 3) Synthesizing, merging, linking, incorporating and integrating solutions to sub-problems in order to formulate the answer to the main problem.

Many human advances in science and engineering have successfully flown from reductionist approaches. The answer to hard problems can be considered a right and definitive approach to the decision variables of the planning problem or the engineering design variables. The so-called' hard solution' is a definitive response to a decision or design variables.' The results of this series of questions are the best answer which illuminates the optimal decision-making solution in a prescriptive, normative, and obligative manner, and the decision-makers' guidelines for finding a solution are clear-cut. Since the assumptions and conditions considered for problem-solving instructions and the best methods of solving the problem are satisfied in the problem situation, concepts such as optimal solution, optimality, and the use of definitive attributes utilized to describe the quality of the solution to a problem are prevalent (Jonassen, 1997).

Similarly, the researcher's experience and innovation in understanding the structure and method of synthesizing solutions to smaller problems can be considered a model for similar problems. The best solutions developed for sub-problems are another output of the hard problem-solving process, the best and right method (Rittel and Webber, 1973). The reductionism approach that the problem solver encounter in hard problems is illustrated in Figure 1.

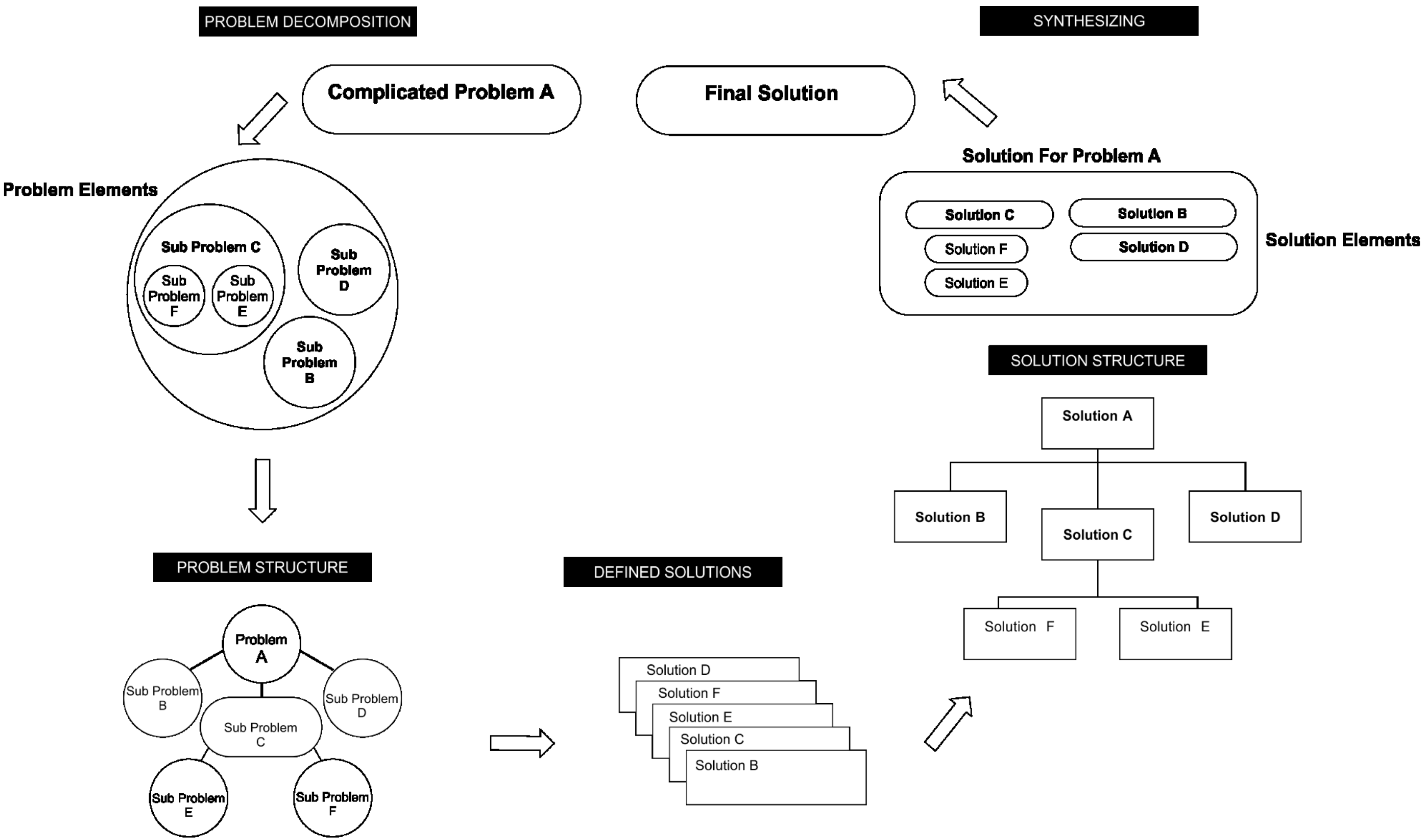

Figure 8. Solving approaches to hard problems

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3. Soft problems

Soft problems deal with problematical and messy situations in which the problem definition itself is perceived as a problem and depends on the individual impression. Soft problems are interlinked to situations in which both definition of the problem and how they are solved are vague (Pidd, 2003). The messy situation of soft problems is complex rather than complicated, dynamic rather than static, and each situation is viewed and interpreted differently and uniquely by the decision maker. In soft problems, the decision maker's perceptions of the problem situation impact the nature of the problem and its solution. In such situations, framing and defining problems that have brought about the mess is regarded as the most challenging and demanding step due to observers' multiple but defensible definitions (Mingers and White, 2010). Because of their social nature, soft problems face a flux of events and ideas that emerge over time. Such a flux creates a problematical situation that is not unique but dynamic and encompasses many conflicting and defensible worldviews. In such situations, the reality is envisaged as a construct of the human mind and is associated with human perceptions of the problem situation (Flood, 2010). Such perceptions require the attribution of meaning to the peripheral social structures (Checkland and Poulter, 2006; Yearworth and Edwards, 2014).

Notably, ambiguity and uncertainty increase in soft problems owing to disagreement on impressions, goals and problem-solving approaches. Thus, in this case, there is a surge in conflicts and differences among the interest groups involved in the problem situation; further, in addition to the content of the problem, the roles involved are also highly significant. In this state, rational decisions will not always lay the proper groundwork for successful and appropriate actions. Therefore, solving a problem is not a rational activity but a social action (Brunsson, 1985). Soft problems have enormous complexities because of their relationship with social situations and interactions with those who create them. One of the objectives of operations research is to tackle these complexities. The thinking about these problems is called soft systems thinking. Soft systems thinking which rests on the changing messy situation casts doubt on the legitimacy of hard systems thinking' view in solving human-oriented problems (Hanafizadeh and Mehrabioun, 2017). Therefore, the approach used to solve soft problems differs from that of hard problems.

3.1. The nature of soft problems

Soft problems must grapple with scant information resources, and their data are uncertain and incomplete (Edmonstone, 2014). Further, soft problems are ill-structured because some of the components of the problem are unidentified. There are several criteria for evaluating soft problems, and assessing problems are also susceptible to personal beliefs and judgments (Jonassen, 2000). In addition to the lack of structure, soft problems are complex problems because the components of the problem change over time. Such changes arise because soft problems are closely related to human beings and social processes. According to Checkland (2005), social processes intertwine people's appreciative systems. Such systems have an impact on the way people make decisions about soft problems. Concerning Checkland's and Vickers's (1965) findings, individuals and groups have diverse experiences. These experiences follow their preceding interpretations, judgments, and perceptions and their reactions to new ideas and events. Such experiences lead to the formation of standards, values, and norms. Such standards and values direct the way individuals make judgments while dealing with problems in a manner that the same objective phenomenon is interpreted and judged differently from diverse perspectives. Such judgments serve as the source of actions in the real world. Such actions will also lead to a change in the real world and exert an influence on future experiences. Such a concept is illustrated in Figure 2.

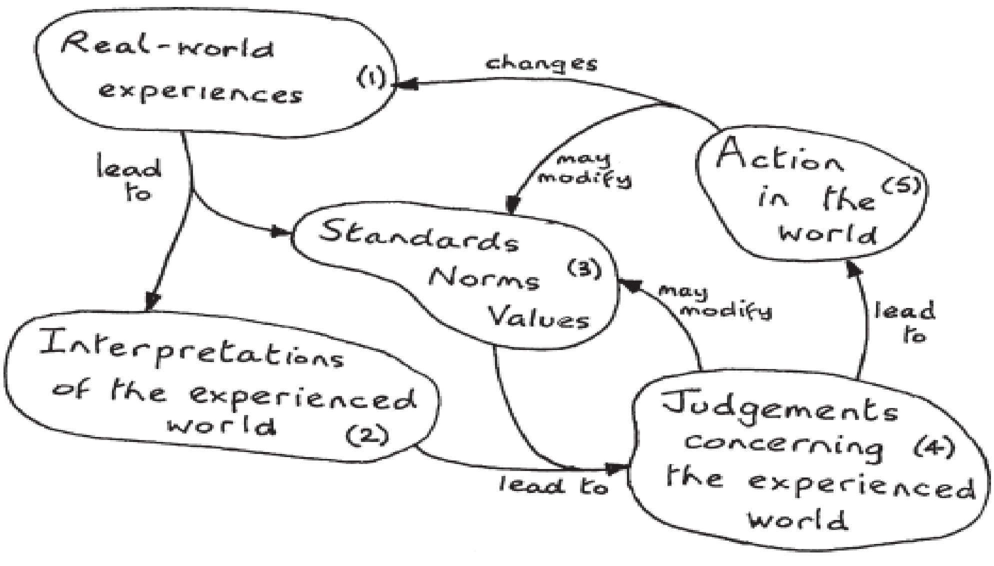

Figure 9. The dynamics of an appreciative system adapted from (Checkland, 2005)

According to Figure. 2, the reason for the complexity and dynamics of soft problems can be explicated as follows. As they are concerned with social processes, soft problems are affected by people's appreciative systems. That is why in the face of a soft problem as a new event, people with different backgrounds come up with diverse standards, values, and norms because they have different perceptions of the past and interpretations. Such differences lead to the formation of several judgments of the same problem, so everybody may have a different way of interpreting the same problem. On the other hand, the multiplicity of standards, norms, and values prompts each person or group to take action to solve a problem; regarding their appreciative systems, such actions lead to a solution to the problem. That is why people have different priorities for problem-solving. Given the importance of appreciative systems in forming soft problems, solutions to soft problems should also consider standards, values, and norms.

Considering the influence of the previous background and experiences on the formation and solving of soft problems, the reductionism approach harms the nature of the problem because a problem originates in history and its past experiences. By disconnecting the problem from its context, reductionism approaches offer an analysis of the problem, regardless of its history and experience. Therefore, holistic approaches should be applied. According to Checkland (2000), a holistic approach should consider people's systems ideas while dealing with messy situations. The emerging property of these systems is purposefulness (Checkland and Poulter, 2010). According to Checkland and Poulter (2010) and Zexian and Xuhui (2010), understanding the purposefulness of individuals should draw on the identification of logical activities and ideal models. Therefore, it can be stated that the problem-solving of soft problems is defined by identifying individuals' systems ideas or ideal models (Hanafizadeh et al., 2017). Considering ideal models is consistent with Checkland and Poulter's (2010) view in analyzing the logical dimensions of the situation of the soft problem and the ideal model of individuals. Therefore, it can be claimed that one of the significant aspects of defining and solving soft problems is to objectify the ideal models of individuals and convert them into a logical phenomenon. The transformation of ideal models into logical phenomena provokes a better understanding of how people think about soft problems.

On the other hand, according to Checkland and Poulter (2010), in addition to the logical analysis of the problem situation, it is indispensable to consider its cultural aspects. As stated earlier, in social processes, people's perceptions of a new problem are influenced by their values. Values, norms, and social and cultural dimensions shape individuals' perceptions of the problem situation. Therefore, cultural phenomena should also be considered critical to understanding logical phenomena while addressing soft problems. Simultaneous attention to logical and cultural phenomena corresponds with Checkland's (2000) phenomenological view of confronting real-world problems. As phenomenology points out, all human activities in the real world rest on thinking about the real world rather than the real world itself. Phenomenology, therefore, seeks to observe, describe, identify, and illustrate the meanings that individuals assign to their actions (Zexian and Xuhui, 2010). Understanding the meanings people attribute to soft problems that stem from their worldviews and values transforms many aspects of these problems into a logical and cultural phenomenon. Transforming such issues into a phenomenon will make it possible for individuals to depart from them and expand their field of view. Logical phenomena generate a better understanding of the mental and logical dimensions of people's thinking about the problem.

Similarly, cultural phenomena improve understanding the individuals' inter-subjective interactions in the problem situation. In addition to making the discussion about the definition and problem-solving of the soft problem more structured, it also contributes to people's better understanding of how they contemplate and perceive these issues. It also leads to a better understanding of the logical aspect of the systems ideas, which are created mentally and actionable in the form of social inter-subjective action while interacting with objectivity. Such understanding requires the participation of interest groups and stakeholders in problem-solving. Stakeholders do not possess the same power level, so understanding cultural phenomena requires the identification of power structures. Stowell and Welch (2012) consider power to be one of the main components of the cultural context of an organization because any change in the problem situation should be studied from the perspective of the power holders in the situation so that their control over the status quo cannot be compromised.

Stowell (1989) uses the metaphor of "commodity" to refer to power in social groups because power is valued by members of the groups and renders the problem situation from one that is not desirable to one that is favorable to them. In his view, awareness of power in social groups cultivates awareness of control strategies used and managed in groups. In addition to raising awareness of informal power, awareness of power in social situations increases a proper understanding of how people exercise power to influence others (Flood and Romm, 2018; Stowell and Welch, 2012). That is why another crucial dimension in understanding cultural phenomena is related to the power structures, as this structure orients people toward self-interest-seeking actions, which people take to achieve their own interests and prevent them from taking other actions that are not to their benefit (Checkland, 1999). It increases the complexity of the problem situation itself. Collective understanding of the ideal models of interest groups with different worldviews (logical phenomenon), along with the understanding of social and cultural aspects (cultural phenomenon), provides a space for creating a social experience by constructing the ideal speech situation (Habermas, 1970). The ideal speech situation is where different groups with different worldviews can freely interact and challenge each other's views. Such challenges result in structuring the definition and soft problem-solving in a collaborative atmosphere. The formation of the ideal speech situation develops a solution on which accommodation is reached among different worldviews over its implementation through a comparison between the problem situation (observation) with the ideal models (theories). Therefore, the soft problem is uncovered and created in both research and action. It is aligned with the idea of Flood's (2010) view. He believes combining systems thinking with action research in solving soft problems is necessary. Here, systems thinking refers to the awareness of the unknown, and action research holds a meaningful relationship with the unknown.

Recreation of the soft problem occurs through reflection because the definition of change actions for problem-solving is built on considering different groups with different ideal models. Therefore, reflection on the problem situation causes the relationship rationally impaired by the system (due to different worldviews) to be reestablished rationally. Such awareness based on reasoning, mutual understanding, and communication affects both logical presuppositions and the intellectual factions' values, norms, and standards. Therefore, in this approach, instead of instrumental thinking that arises from instrumental actions (Checkland, 1984; Jackson, 1990), some form of communicative rationality (Huaxia, 2010) grows out of communicative actions (Habermas et al., 1985), which promotes the development of unforced agreements (Habermas, 1970) to solve soft problems and improve their situation.

The collaborative nature of problem-solving leads to a solution that rests on the common discourse derived from shared thought and communication, not a language that mindsets have spoken with or conversed with others (Christis, 2005). Therefore, through argumentation, a system of common words is generated, and the relationship between dissimilar social groups with diverse ideal models is reconstructed through communication and understanding. Argumentation brings about the reproduction of new values and assumptions that incites the emergence of new standards in social groups. Therefore, problem-solving leads to a new reality in which different groups can accommodate and live with different worldviews. In what follows, we will consider how the help researchers mentioned earlier solve soft problems.

3.2. The soft problem solution

Using the Soft Systems Methodology (SSM) as one of the most successful problem-solving methodologies in dealing with messy situations has attracted the attention of many researchers and practitioners worldwide. SSM was developed using action research (Checkland and

Holwell, 1998). Therefore, it is premised on a researcher who intervenes in a problem situation, intends to think about the problem in line with the SSM guidelines, and seeks to improve it using a series of courses of action. In this case, the researcher or researchers are striving to ascertain a way of declaring the worldview of the interest groups in the problem situation.

Using analyses 1, 2, and 3, researchers are trying to understand better the political and social contexts of the problem situation. Then, they utilize the models as intellectual devices to raise questions about the problem situation and adopt both logically desirable and culturally feasible actions. Therefore, it can be argued that solving soft problems requires an inquiry into the problem situation, the declaration of systems ideas and their worldviews, awareness of the logical and cultural phenomena, the creation of debate and discussion, and finally, the improvement of the perceived problem situation. Therefore, soft problem-solving can be shown in Figure 3

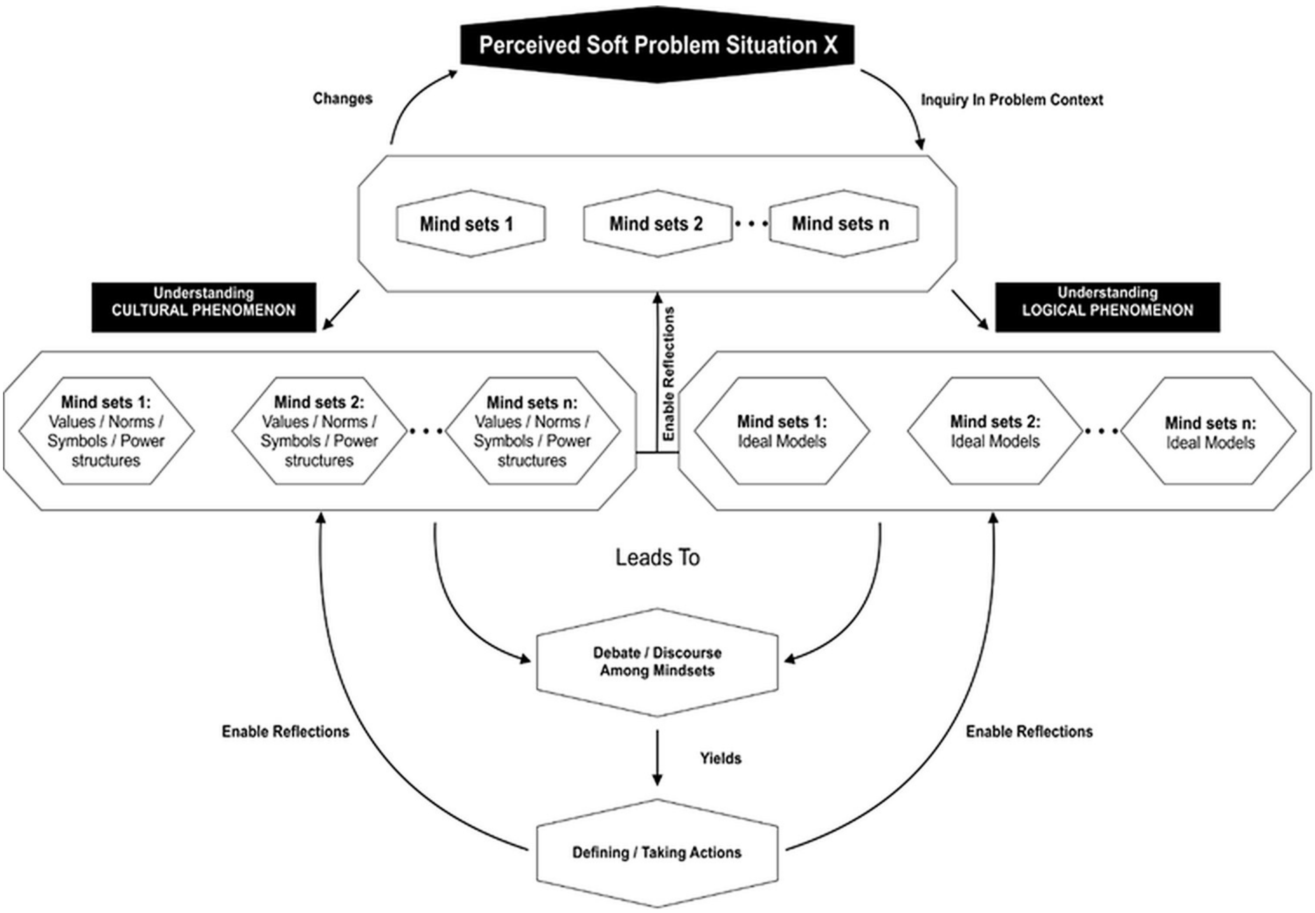

Figure 10. The process of the soft problem solution

Based on Figure 3, the inquiry into the problem situation familiarizes the researcher with all mindsets. Such an intervention will allow all mindsets to participate in problem-solving as frequently as possible. Moreover, a better understanding of the thought factions requires a better understanding of norms, power disposition, and values effectively in the appreciative process of different interest groups. Therefore, it is essential to examine the subjective dimensions effective in interpreting the problem situation through logical phenomena and norms, values , and power structure in the form of cultural phenomena. Awareness of logical phenomena is cultivated by constructing ideal models (Hanafizadeh et al., 2021). According to Wilson (2001), the ideal model in soft systems thinking should be an activity system comprised of concepts and verbs and logical connectivities among them. Therefore, to objectify the ideal models of each mindset, it is necessary to create activity systems.

On the other hand, another subsequent feature of such a system must be the purposefulness of each mindset (Hanafizadeh and Mehrabioun, 2019; Hanafizadeh and Mehrabioun, 2020). Awareness of cultural phenomena is also realized by identifying roles, values , and norms in the problem. On the other hand, according to Hatch and Cunliffe (2013), awareness of the symbols can also afford a better understanding of cultural phenomena. Therefore, in addition to identifying values and norms, it is better to appropriately understand the symbols in the context of the problem situation. Similarly, it is essential to examine issues such as power structures in the inquiry of the problem situation (Champion and Stowell, 2001) because in organizations with asymmetric power structures, powerful and dominant groups can exercise influence on discussions and debates and drive the outcomes of these meetings toward their individual goals. Awareness of logical and cultural phenomena paves the way for the researcher(s) to theorize. Now the space is provided to raise the stakeholders' and interest groups' awareness and understanding of the problem. Stakeholders' participation in solving the problem and their awareness of the ideal models of other thought factions and their thinking allows space for discussion about the problem solution and, in the case of SSM, form a human activity system (HAS) (Hanafizadeh et al., 2021).

Structured discussions seek to compare theories (the results deriving from identifying logical phenomena and cultural phenomena) with observations (the objectivity of the problem situation). In addition to challenging institutionalized assumptions in the view of stakeholders about the problem situation, such debates mould actions that not only improve the problem situation but also promote all stakeholders' understanding and awareness of the problem situation. Such a solution is a purposeful system that rests on concepts and verbs that all stakeholders acknowledge. In such a system, at first, the ideal models of each interest group have become a purposeful activity model which rests on verbs used to describe systems ideas. Then, through discussion and debate among stakeholders, an accommodation has been made on common concepts and verbs. Therefore, change and problem-solving actions are created based on a system of common concepts and verbs. Such a system also promotes the commitment of stakeholders to problem-solving since it is intended to address the problem situation and improve it. On the other hand, the awareness of each interest group's logical and cultural phenomena of the problem situation encourages their reflection on the problem situation, generating a shared social experience.

4. The quality of solutions

As was earlier stated concerning hard problems, the structure of the solution is influenced by the structure of the problem. The impact of the structure of the solution on the structure of the problem makes it possible for the knowledge derived from the solution of hard problems to attain a replicative nature and acquire applicative actions (Edmonstone, 2014). The replicative aspect of knowledge enables us to use repetitive and routine activities in problems with the same structure (Edmonstone, 2017). In this case, the use of intuition is minimized. In the applicative actions aspect, the individual seeks to extend the learning derived from the problem solution in the form of prescriptive approaches to situations and conditions with the same structure. Such an issue transforms the knowledge needed to solve hard problems into programmed knowledge (Revans, 2016). Therefore, existing knowledge bases for solving hard problems are constantly evolving. That is why solving hard problems involves individuals who are conscious of these knowledge bases and qualified enough to reduce hard problems to sub-problems, solve sub-problems, and synthesize sub-problems into a final solution. Such people should have an appropriate command of technical knowledge in the puzzle situation.

Therefore, it can be claimed that the problem solver's qualifications and awareness of the problem structure, along with the mastery of technical knowledge (Edmonstone, 2014), ensures taming the hard problems and their solving. In this set of problems, knowledge accumulated by the solution is the type of knowledge independent of the person and can be confirmed and evaluated by others. On the other hand, the impact of the structure of the solution on the structure of the problem allows us to establish a direct and causal relationship between the input and the output.

In soft problems, problem-solving requires structuring the problem by creating an ideal speech situation. A proper understanding of the perceptions of all interested groups is needed to create an ideal dialogue climate. Such an approach is shown in Figure 3. Such a solution will allow space for the stakeholders' participation and a collective solution. Therefore, it is feasible to use their views in solving the problem. Different stakeholders intervene in the problem situation and seek to take action to improve the problem situation regarding collective learning. In this state, the solution is a human activity system, a system of concepts and verbs that all the interested groups accept. During its implementation, there is accommodation among all the interested groups (Hanafizadeh et al., 2021). Therefore, in this state, the solution is not a definitive solution, but there is a distinct procedure consisting of concepts because logical and cultural phenomena have been simultaneously considered in creating this solution. Therefore, in addition to the logical dimensions, the cultural and inter-subjective dimensions are also involved in its formation. In this state, the solution is a shared meaning system. Consequently, like the problem, the solution is a reality that is collectively enacted.

5. Discussion

This research attempts to investigate the nature of the problems. Therefore, the nature of problems and their various aspects, including the formulation of the problem, the approach to confronting the problem, the problem-solving process, and the type of problem-solving for each of the two extreme points of problems (hard problems and soft problems), have been investigated.

Hard problems are problems for there is a general agreement on the formulation and the process of solving among interest groups. Hence, in this set of problems, the ends and the means are transparent. There is also an appropriate cognitive capacity to analyze problems. The main goal of this set of problems is to find the best solution (Tarter and Hoy, 1998). In hard problems, the structure of the problem creates a solution structure. Therefore, the problem-solving approach is based on the reductionism approach derived from breaking down the problem into small sub-problems and independently solving each sub-problems. The type of solution in the puzzle is definitive and optimal, and the problem-solving is carried out by providing an obligative and prescriptive solution. Creating obligative rational solutions can be appropriate for engineering, natural, and medical sciences. What is expected in these sciences is their confrontation with non-social problems. These problems can be complicated but are less complex because, in this set of problems, there are not any different historical experiences (Vickers, 1965), any diverse interpretations of the same phenomenon (Flood, 1998), and any pursuit of satisfactory approaches (Simon, 1973) in solving the problem. Therefore, the solution structure is similar to the problem structure.

Soft problems are the opposite of hard problems. Unlike hard problems, these problems cannot be tamed, and due to the ill-structuredness of the problem, it is difficult to assign a structure to the solution. The ill-structuredness of this set of problems arises from the fact that there is no identical interpretation of the problem definition and its solutions among the stakeholders. Therefore, the problem solver needs to simultaneously define the problem and create solutions because soft problems deal with social situations, in which each situation is formulated differently and uniquely by the decision maker (Pidd, 2003). The soft problem is a social construct that has been transformed into an unstructured problem by different perceptions of its stakeholders and their different interpretations of the problem situation on the one hand and the language slippage of individuals from an identical situation. According to Checkland and Poulter (2010), the data are the meanings that individuals attribute to data of a social context. Different judgments are made due to different appreciations of people from the same situation. Such an issue reduces the likelihood of a common interpretation of data in the problem situation. Therefore, the lack of information in such situations adds to the complexity of these problems. According to Simon (1976), the lack of information and ambiguity is the most crucial factor in the ill-structuredness of this set of problems. This study considers the approach that grapples with these problems through a holistic approach. According to Checkland and Casar (1986) and Vickers (1965) views, individuals' perceptions are influenced by their historical experiences, values, and assumptions. Thus, soft problems are concerned with different meanings assigned by the stakeholders. In order to formulate and solve soft problems, it is essential to identify the standards, values, and norms on which individuals base their judgments. The identification of standards depends on the awareness of the ideal models of the mindsets; likewise, understanding values requires analyzing the political, social and cultural contexts in the problem situation.

Such an issue renders the type of people's view of soft problems and the context in which the problem occurs into logical and cultural phenomena. Therefore, the problem solvers can take neutral positions, distance themselves from them, and expand their field of view. In this way, an opportunity is provided for debate and discussion among different perspectives, and a space is developed for translating a messy situation into an ideal speech situation (Habermas, 1970). Creating such a situation prepares a space for provoking thought and problem-solving. Such an issue brings about 6 achievements in solving soft problems.

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1) In soft problems, due to the lack of structure in the solution, there is ambiguity in defining the problem and its solution. Dialogue between different groups reduces ambiguity in defining and solving the problem. 2) In soft problems, individuals hold different standards, values, and norms; consequently, creating an ideal speech situation raises the awareness of different groups of standards, values, and norms of other groups and enables them to call them into question. 3) By challenging assumptions, values, and norms, thought is replaced by reflection because people do not just think about the status quo, but their past experiences and perceptions of issues are criticized during an argumentation; additionally, they are motivated to reflect on their way of thinking. Such reflective learning leads to a rational reconstruction of communication that the system has rationally broken down. 4) The ideal speech situation creates a shared social experience. This shared social experience orients problem-solving toward benefiting from communicative rather than instrumental action and prevents forced agreements in the problem situation. 5) Such communicative actions transform the solution into a system of common concepts and verbs with a shared agreement on their meanings. The solution is based on the language of the people's thoughts, not a language that they have spoken with or conversed with others. (6) As ideal models are created based on concepts stemming from the individuals' purposefulness to improve the state, solutions are not definitive answers but distinct procedures consisting of concepts and verbs that inform the problem's solution. Moreover, since the study of cultural dimensions and inter-subjective have been involved in the formation of the procedure, it is a system of shared meanings. Thus, the solution is a social reality like the problem that is collectively enacted.

Regarding the current research findings, in dealing with soft problems, understanding the perceptions of all thought factions is required to create an ideal speech situation. Such an approach is shown in Figure 3. Such an issue will allow space for the participation of all stakeholders and a collective solution. Such a solution is a system of concepts and verbs acknowledged by all the thought factions, and there is an accommodation and inter-subjectivity over its implementation among all mindsets.

Considering those mentioned above, it is possible to illustrate the differences between hard and soft problems in the formulation and problem-solving phases in Tables 1 and 2.

Table 8. The differences between hard and soft problems in the formulation phase

Types of problems	Hard problems (structured-tamed)	Soft problems (messy, ill-structured)
Agreement on the definition of the problem	Yes	No
The domain of the definition of the problem	Clear	Unclear
The source of uncertainty	Limitations of technology and measurement devices	Irrational behavior of individuals involved in the problem situation
Type of data	Clear	Deficient
Nature of data	Independent of the context	Influenced by the context
The root cause of the problem	Known or can be explored through a causal relationship	Unknown and the unlikely and far-fetched relationship between cause and effect
Structure of the problem	Precise and predictable in time intervals	Unclear and unpredictable in time intervals
Problem situation	Repetitive and replicative	New and unique
Dimensions of the problem	Complementary	Contradictory
Success in the problem	Identical interpretations	Diverse interpretations
Indices of the definition of the problem	Objective and free from subjective judgment	Subjective and intertwined with personal judgment
New problems	In line with completing the old problems	Generated by old problems

Table 9. Differences between hard and soft problems in the problem-solving phase

Type of problems	Hard problems (structured-tamed)	Soft problems (messy, ill-structured)
Approach to problem-solving	Reductionism (mechanistic)	Holistic (organic)
Problem-solving process	Agreement	Lack of agreement
The objective of the problem-solving	Complementing the previous assumptions	Challenging the previous assumptions
Structure of the problem-solving	Influenced by the structure of the problem	Influenced by the mental structure, basic assumptions, and framework of ideas
Nature of the problem-solving	Rational activity	Social action
The audience of the problem-solving	General and with identical interpretations	Interested groups with similar interpretations within similar groups and contradictory interpretations outside groups
Type of solution	Definitive/optimal/obligative/normative	Procedural/ instructions based on human activity system/Meaningful procedure of concepts and the relationships among them
Modeling of the problem-solving	Real models	Ideal models (representing the way individuals think about the real world)
Philosophical assumptions used in the problem-solving	Positivistic assumptions	Phenomenological assumptions
The criterion for reaching the solution	Definitive/influenced by assumptions	Judgmental/ influenced by values, norms, and standards
The criterion for evaluating the solution	Objective	Subjective/ Judgmental
Quality of the solution	Right/wrong	Satisfactory and relative (Better or worse, appropriate or inappropriate, adequately good or bad)
The pattern of the solution	Linear	Fluid, fuzzy, and non-linear
Generalization of the solution	Independent of the situation and generalizable to similar situations	Dependent on the situation and not generalizable to similar situations
Action of problem-solving	Instrumental	Communicational
The knowledge accumulated by problem-solving	Repetitive and applicative	Interpretive and associative/practical
Resistance to changes in problem-solving	Low	High
How to reach the solution	Empirical and rational experience	Shared social experience
The outcome of the solution	Clear (through causal relationship)	Unclear
The role of the problem solver	Taming and managing	Leadership, challenging the assumptions and changing idea frameworks

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According to Table 1, the differences between soft and hard problems in the definition phase of the problem derives from their dependence or independence on a situation. In hard problems, since the problem is independent of the situation, it is not influenced by the problematical situation. It also reduces uncertainty in the problem. Reduction in uncertainty in the problem enables the researcher to unravel causal relationships and predict the future of the problem.

In contrast, due to their dependence on the problem situation and the social processes, soft problems are liable to be influenced by numerous interpretations and judgments. Additionally, soft problems grow out of old problems and are susceptible to previous perceptions of individuals. That is why they are intertwined with mental indices and judgments. Therefore, the possibility of predicting and decisively resolving the problem is significantly reduced. That is why the uncertainty in the problem is elevated, and the researcher encounters contradictory rather than complementary components.

According to Table 2, diverse approaches are adopted to solve hard and soft problems. Hard problems require linear, reductionist, and rational methods. Since there are identical interpretations of the problem-solving methods, the criteria for evaluating the response to hard problems are also definitive. The purpose of solving the problem is to complement the previous assumptions. In hard problems, the criteria for evaluating the solution are objective and entirely transparent, and the accumulated solutions can be generalized to similar situations. Therefore, the outcome of the solution is specific, and the derived knowledge is repetitive and applicative. In soft problems, the nature of problem-solving is considered a social activity rather than a rational activity because problem-solving encounters different groups that have identical interpretations of the problem within their own group, but their inter-group interpretations are diverse. Therefore, the criterion for achieving a solution is judgmental and influenced by the appreciation of individuals; therefore, reaching a solution requires the participation of different groups and creating a shared social experience. Such a process also requires that the problem solver hold leadership skills and be capable of challenging the mental assumptions of individuals. Therefore, the solution structure of the problem is influenced by the mental structure of individuals; hence the quality of the solution is not definitive and leads to satisfactory patterns. In soft problems, problem-solving is not based on standards imposed but on a learning system. Therefore, it can be argued that in contrast to hard problems, a definitive solution is not an optimal answer in solving soft problems, but rather a shared meaning system is preferred in order to create a learning system. Therefore, a solution is chosen, built on attributing meaning to ideal models of individuals in the problem situation and a better understanding of their related activities by identifying the problem's cultural and social dimensions of the problem.

6. Conclusion

Problems can be plotted across a continuum with two extremes of hard to soft. Problem-solving involves defining the problem, selecting an approach to the problem, and configuring the research process. The scholar's philosophical assumptions influence the correct way to follow such a process. That is why prior to the implementation of the above steps, the philosophical assumptions of the researcher need to be adequately explained. The research results reveal that there is still incommensurability between the methodology and the nature of the problem (Flood, 1989; Hanafizadeh and Mehrabioun, 2017). Therefore, researchers' use of methodology, methods, and techniques is not consistent with the nature of the problem. Researchers mostly focus on the mechanical use of techniques and methods instead of understanding the nature of the problems. This research strongly states that before dealing with a problem solution, it is essential to recognize the nature of the problem. Thinking about the nature of the problem serves as a precondition for thinking about the problem. It leads to the fact that instead of mechanically undergoing a sequence of steps of methodology, the researcher's approach to problem solution must be an attempt to identify the problem's nature better and better adapt the methodology to the problem. It makes researchers encounter the soft problem on a problem oriented rather than a user-oriented basis.

For this reason, this research aims to help researchers strike the right balance between the nature of the problem, the problem-solving method, and the applied methodology. To achieve this purpose, the difference between the nature of soft and hard problems was considered in the first question. The results of this study indicate that the structure leads to the difference between the nature of soft and hard problems. In hard problems, the structure is distinct and varies with a predictable trend in time; soft problems do not follow a specific, transparent, and predictable structure. The existence of a structure in hard problems makes the definition of the problem and the definition of solutions capture the identical readings and interpretations of the various stakeholders. In this way, uncertainty in problem-solving is minimized. The problem solvers' confidence in the structure of the problem transforms the researchers' concern into an accurate explanation of the results of problem-solving, the inclusive assurance of the accuracy of the accumulated information, and the choice of a solution with the most excellent convergence with the problem structure. Therefore, the researcher's concern in this set of problems is identifying, prioritizing, evaluating options, and choosing the best problem-solving instructions. In this state, the problem-solving approach for hard problems, as shown in Figure 1, involves going through three stages: 1) understanding the structure and assigning structure to the sub-problems during the process of decomposing the main problem into sub-problems; 2) assigning the best solution to any of the sub-problems to solve them or develop a solution instruction for a sub-problem; and 3) how to synthesize, interconnect, link, and integrate the solutions of sub-problems to formulate the answer to the main problem.

In soft problems, the structure of the problem is uncertain and unpredictable because the fluid context of the problem influences it. Therefore, uncertainty increases in problem-solving. In this set of problems, the researchers' efforts should be focused on understanding the problem's context instead of knowing the structure of the problem. The results of this study also indicate that to understand the context of the problem, the researcher's approach to the configuration of the research should be oriented from the positivist and rational approaches needed in hard questions toward phenomenological approaches. Such an understanding should be built on identifying logical and cultural phenomena in the context of the problem. An understanding that focuses on stakeholders' participation in the problem situation. The logical phenomena are identified by constructing the ideal models of the interest groups in the problem situation.

Understanding cultural phenomena occurs through understanding standards, values, norms, power structures, and symbolic phenomena in the problem situation. The collective understanding of the ideal models of interest groups (logical phenomena) and the understanding of social, political, and cultural aspects (cultural phenomena) lay the groundwork for forming a shared social experience through constructing an ideal speech situation. Such a situation will lead to structuring the definition and solving soft problems. Now the soft problem has acquired a better structure because discussions and debates have inspired different groups to reflect on the rational and cultural phenomena of the problem situation and inspired the same readings and interpretations of the problem context.

The second question addresses the difference in the quality of solutions for hard and soft problems. The results of this study demonstrate that since the problem-solvers of hard problems are aware of the structure of the problem, their attempt to solve the problem is focused on identifying the causal relationships in the problem rather than assigning structure to the problem. In this case, owing to the same problem interpretation, the knowledge derived from the solution is independent of the person and can be confirmed and evaluated by others. Therefore, the answer is a normative, definitive solution obtained by taming the problem the researcher.

In soft problems, there is no structure in the problem, so the researcher's concern is to create such a structure. In such problems, instead of identifying causal relationships in the problem situation, the researcher attempts to analyze the situation of the problem through rational and cultural recognition of the actor's actions in the problem situation. Unlike the solution to hard problems, the solution is not a definitive answer but a distinct procedure consisting of concepts and verbs that seek to conceptualize the purposeful actions of multiple stakeholders because logical and cultural phenomena have been simultaneously considered in creating this solution. Therefore, in addition to the subjectivity dimensions, the cultural and inter-subjective dimensions are also involved in its formation. In this case, the solution is a shared meaning system. Consequently, like the problem, the solution is a reality that is collectively enacted.

For this reason, the quality of the solution draws on its capability of constructing a situation where understanding the purposefulness of the actors and stakeholders of the problem situation serves as the basis of the problem. In this case, the quality of the solution is defined based on the explanation and understanding purposefulness of the interest groups and the representation of human actions and cultural phenomena of the problem situation. The more appropriately the solution can describe the problem situation, including the purposefulness of the interest groups (ideal models), social relations, social norms, power structures, and symbolic phenomena in the problem situation, the higher quality it can achieve. So, the quality of the solution derives from its capability of conceptualizing purposeful actions along with the values and norms affecting social action.

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The Optimal Policy for the Evolution of Total Quality Management for Improving Environmental Indicators Using Fuzzy System Dynamics

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ABSTRACT

Nowadays, global competition has penetrated all parts of the world and all businesses. One challenge facing industries is balancing economic and social progress with environmental protection. While industries have understood the importance of sustainable development, they may not know how to operationalize the concept. Industries need to incorporate environmental aspects into the production process and product design to avoid exploitation of unsustainable and adverse environmental impacts. The result of such conditions is the ever-increasing and endless increase in customer expectations. In recent years, the green economy has been proposed as an emerging concept with the aim of sustainable development. The company's sustainability is achieved at the intersection of economic growth, environmental protection, and social responsibility. The current research is applied from the objective point of view and descriptive from the method point of view. The subject of this research is a production organization in the field of the automobile industry in Shiraz. The research method based on the system dynamics approach was considered because by using this method, different policies can be designed, and the results of each policy can be evaluated. The results show a strong relationship between total quality management and environmentally friendly production systems. According to the results of offensive manufacturing industries, TQM, directly and indirectly, affects environmental sustainability. Based on the research findings, it can be said that the overall effect of efforts to improve the soft factors of comprehensive quality management is more significant in enhancing environmental indicators.

Keywords

Environmental indicators, Prevention of air pollution, Reduction of energy consumption, Fuzzy system dynamics.

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1. Introduction

Corporate sustainability is achieved at the intersection of economic development, environmental protection, and social responsibility (Engert et al., 2016). Supporting such a claim is not easy. A local or global value chain system must change from its traditional management approach to sustainable production. It is evident that this correlation, in addition to the acceptance of the concept of sustainability by organizations, requires some organizational paradigms, management philosophies, processes, and tools that can effectively support the organization in implementing this new approach (Aquilani et al., 2016). These practices can be found under different labels and fields, such as industrial ecology (Despeisse et al., 2012). Green production is the most crucial concept in this field, although ideas such as environmentally friendly systems have also been formed in previous years.

Determining the appropriate management system to ensure sustainable development is an essential issue for small and medium enterprises, not only due to the pressure of stakeholders but also from the development of enterprises themselves (Burke & Gaughran, 2007). Companies need a proper management method and practical framework to identify and implement sustainable development plans. Each company's sustainable development strategies differ from those of other companies due to budget, resource limitations, flexibility, structure, number of customers, market, and expertise (Alshawi et al., 2011). Assessing companies' sustainability is the production of tools that guide the organization toward sustainable practices and show how these organizations contribute to global sustainable development (Moldavska and Welo, 2019). Sustainability assessment is further defined as a decision support tool that guides decision-making towards sustainability (Bond and Morrison-Saunders, 2013). Sustainability assessment is usually used as an umbrella for different methods, processes, frameworks, and tools that focus on measuring or promoting sustainability at different levels (country, city, or organization). Objectives of evaluating the sustainability of information production for decision-making, structuring complexity, and social learning (Waas et al., 2014) as well as supporting decision-makers, and facilitating the identification of actions taken to contribute to sustainable development (Moldavska and Welo, 2016) have been mentioned. In the production sector, there are several tools for evaluating sustainability, some of which measure one dimension and some measure two or three dimensions of sustainable development.

Environmental sustainability, which is also referred to as the green aspect of sustainability, is defined by Goodland as the unlimited factor of life support systems worldwide (Goodland, 1995). The environmental dimension refers to the conditions surrounding human life. The

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environment is significantly affected by businesses. Companies should effectively monitor how their activities affect the environment and reduce the damage caused by it (Chang and Cheng, 2019). Sustainable development as a general concept leads to very vague valuable guidelines. Therefore, developing and applying indicators, which provide the necessary measures at the action level, is critical (Johnston et al., 2007). Management will be immersed in ambiguity, contradiction, and incomplete and non-comparable information without agreement on the identification and principles of measuring sustainable production indicators. Therefore, these indicators must achieve sustainable production (Ranganathan, 1998). According to the definition provided by the European Environment Agency, an environmental indicator is a representative of the observed value of a phenomenon under investigation (Herva et al., 2011). From the sustainability perspective, indicators should provide information about the main characteristics of the effectiveness of products and processes (Sikdar, 2003). Identifying environmental indicators for production and service processes, the possibility of comparing environmental performance over time, highlighting optimization potentials, obtaining and pursuing environmental goals, identifying market opportunities, benchmarking against other companies, or communicating results in It provides environmental reports (Azapagic and Perdan, 2000). The most significant environmental indicators in manufacturing companies are:

Prevention of air pollution: Among all current environmental issues, climate change seems to be the most critical issue, which poses a significant threat to human development (Tang and Yeoh, 2007). Billions of people are exposed to natural disasters caused by global climate changes; these changes threaten human life, damage infrastructure, and resources, disrupt economic activities, and disrupt the process of social development. Slow (Pelling et al., 2004). Several studies have shown that reducing greenhouse gas production is the most critical measure of green production (Thanki et al., 2016). Although other greenhouse gases have global warming potential, carbon dicrucialthe most crucial factor in global warming (Herva et al., 2011).

Recycling of materials: Recycling materials refers to the issue of knowing the time and place of waste production and checking whether waste can be used as an input of resources elsewhere due to the system's complexity (Despeisse et al., 2012).

Waste reduction: waste management is in the environmental aspects of sustainability and is one of the most effective ways to achieve sustainable production processes. Manufacturing industries face many challenges, including energy and water efficiency, greenhouse gas emissions, carbon footprints, and work days due to worker injuries and illnesses. All these factors collectively increase the amount of waste in the production process in a way that significantly impacts the lowest level of sustainability and future growth of these industrial facilities (Latif et al.,2017). Equipment maintenance and appropriate actions in managing the production environment reduce waste production.

Saving energy: Manufacturing industries consume a lot of energy and limited materials (Cai et al., 2018), which leads to the creation of much waste and seriously damages the environment (Ma and Cai, 2018). Consumption of energy resources to produce power, heat, or cooling has led to various environmental and social problems (Bose, 2010). Energy efficiency is the first and most important predictor of sustainability. The sustainability of a company or organization largely depends on the efficient use of energy (Latif et al., 2017). Therefore, improving energy efficiency and improving environmental performance as much as possible is a fundamental problem to be solved (Mikulčićet al., 2013). Energy saving contributes significantly to improving the sustainable development of the industry (Lv et al., 2019). The main factors that affect energy efficiency in manufacturing industries are lighting, heating, air conditioning, steam, process heat, pumps and fans, motors, air compressors, and cooling towers or chillers (Chengalur et al., 2013).

Saving water consumption: Water consumption refers to the amount of freshwater used to produce goods and services. The importance of this issue is to the extent that in the set of environmental indicators of sustainable development, an index called water footprint (WF) has been defined, which refers to the total volume of freshwater used for the production of consumer goods and services at the national level (Hoekstra and Chapagain, 2006). Regarding this criterion, issues such as the rational use of drinking water with a focus on reducing consumption through the installation of smart devices and the reuse of rainwater, sewage, and water from air conditioning condensate in watering gardens are suggested (Carneiro et al., 2012).

Reducing the consumption of dangerous, toxic, and harmful substances: The increase in the production of chemicals and their use in various industrial processes is one of the signs of an industrial society. The side effects caused by dangerous waste materials are very different and diverse in the health and personal health of employees and environmental fields. These effects are short-term and severe (acute poisoning by dangerous chemicals). Another category of health effects is long-term effects, which appear over a relatively long period and are mostly related to the characteristics of poisons, bioaccumulation, carcinogenicity, mutagenicity, teratogenicity, and chemical substances (Hietschold et al., 2014).

Today, global competition has penetrated all parts of the world and all businesses. The result of such conditions is the ever-increasing and endless increase in customer expectations. Customers always demand more durable, reliable products at the most economical price (Raj and Attri, 2011). These pressures have led organizations to continuous improvement, increased flexibility, and increased quality (Hietschold et al., 2014). Quality is essential for the survival and competitiveness of organizations (Sower, 2010). Among the various improvement and quality management systems, their fourth level, total quality management, has attracted the attention of many researchers and experts worldwide. Total quality management is a systemic philosophy that emphasizes continuous improvement in the organization to provide superior value to customers (Li et al., 2008). Total quality management can be defined as an integrated effort to achieve and maintain high-quality products based on maintenance, continuous process improvement, and error prevention at all levels and in all tasks of the organization to reach customer expectations and even exceed those expectations defined (Flynn et al., 1994). Total quality management is a multidimensional concept. In the technical or challenging aspect, production techniques and work process control are used to solve the problem. In the soft part (including behavioral and social factors), issues such as company culture, management commitment, environment, and work teams are examined. (Psomas and Fotopoulo, 2010). The implementation of total quality management is complex. It has a complicated process, and its results are not easily obtained (Mosadegh Rad, 2006). Identifying and measuring the critical success factors is a prerequisite to controlling the implementation process and increasing the chances of success. The essential success factors can be seen as the conditions, methods, and enablers that drive the organization's success and must exist or be developed to ensure the successful implementation of total quality management (Sila, 2007). The lack of organizational information about the critical success factors of total quality management hinders its practical performance (Psomas and Fotopoulos, 2010). The essential factors of success based on the review of previous studies and their division are listed in table 1. The results resulting from the implementation of total quality management based on Agrawal's business excellence model include five items of impact on society (IOS), human resource satisfaction (HRS), customer satisfaction (CUS), supplier satisfaction (SUS), and specific business results of the organization (BSR) is considered (Khanna et al.,, 2004).

Table 10. The key success factors of total quality management in previous research

Group	Key Success Factor	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20
Soft management	Top Management Commitment and Leadership (TMCL)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Human Resource Management (HRM)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Teaching and Learning (TL)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Soft communicational	Customer Focus (CF)		*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Supplier Partnership (SP)				*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*
	Culture and Communication (CC)	*				*			*				*		*			*	*		*
Hard	Process Management (PM)	*				*	*	*	*	*	*	*		*	*		*	*	*	*	*
	Information and Measurement (IM)	*	*	*	*	*				*	*	*	*	*	*	*	*	*	*	*	
	Strategic Quality Planning (SQP)	*		*		*	*	*	*	*		*	*	*	*				*		*
	Benchmarking (BE)	*	*	*	*				*		*		*		*	*			*		
	continuous improvement (CI)		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*		

A_1:(Porter and Parker, 1993), A_2:(Huq and Stolen, 1998), A_3:(Zhang, et al., 2000), A_4:(Sila and Ebrahimpour, 2002), A_5:(Chin, et al., 2002), A_6:(Claver, et al., 2003), A_7:(Conca, et al., 2004), A_8:(José, 2005), A_9:(Lewis, et al., 2006), A_{10}:(Singh and Smith, 2006), A_{11}:(Sila, 2007), A_{12}:(Khamalah and Lingaraj, 2007), A_{13}:(Fotopoulos and Psomas, 2009), A_{14}:(Ismail Salaheldin, 2009), A_{15}:(Talib and Rahman, 2010), A_{16}:(Sadikoglu and Zehir, 2010), A_{17}:(Jayaram, et al., 2010), A_{18}:(Talib, et al., 2011), A_{19}:(Calvo-Mora, et al., 2014), A_{20}:(Bolatan, et al., 2016)

Quality is not a technical function but a systemic process that extends throughout all stages of business (Raj and Attri, 2011). One of the reasons for the failure of TQM in organizations is the lack of self-evaluation and the transformation of the resulting information into specific goals and operational plans. In general, total quality management is based on a mental model described (Khanna et al., 2004), and the critical success factors are latent and ambiguous variables that cannot be measured directly; this problem may be a failure to provide anticipated solutions can lead to complex situations. Simulation can help realize TQM (Jones and Crowe, 1996). Systems dynamics, as one of the simulation methods, enables managers to understand a complex and dynamic system (Bauer et al., 2000). This science, which shows the interactions between the variables of a system based on feedback structures and examines the relationships between related concepts over time, can be used to create appropriate designs and computer simulations (Forrester, 1993). In every SD model are linear or non-linear equations that define the relationship between variables and their derivatives. In practice, determining such equations is not an easy task and estimating its parameters requires a significant amount of data. (Baradaran and Keshavarz, 2015). On the other hand, variables or parameters of systems dynamics models may belong to uncertain factors. When we are faced with ambiguous and linguistic variables, we are in a situation full of uncertainty that makes quantification difficult; the development of systems dynamics is necessary to overcome this problem (Sabounchi et al., 2011) since human judgment and ambiguity are sources of fuzzy uncertainty, fuzzy logic can be used to increase confidence in the validity of results for modeling dynamic systems (Baradaran and Keshavarz, 2015), fuzzy logic in Modeling the human behavioral pattern is instrumental because most of the decisions and behavior of humans are based on the command of language.

This study presents a model for evaluating and monitoring TQM and investigating the effects of managers' decisions in this area on environmental indicators.

2. Literature review

To check the literature review, the papers related to the research topic were reviewed and summarized in Table 2.

Table 11. Literature review related to the relationship between total quality management and green production

Authors Name	Article Name	Type	Relation
(Klassen and McLaughlin, 1993)	TQM and environmental excellence in manufacturing	Survey study	+
(Corbett and Cutler, 2000)	Environmental management systems in the New Zealand plastics industry	Case Study	+
(Curkovic, et al., 2000)	Investigating the relationship between ‹Total Quality Management and environmentally responsible production	Structural equation	+
(Isaksson, 2006)	Total quality management for sustainable development	Case Study	+
(Vais, et al., 2006)	Pure and green in a Romanian tissue and secondary slate factory	Case Study	+
(Simpson and Samson, 2010)	Environmental strategy and minimal production waste: a review of supplements	Statistical Methods	+
(Yang, et al., 2010)	The mediating effect of environmental management on manufacturing competitiveness: an empirical study	Statistical Methods	+
(Vinodh, et al., 2011)	Lean production tools and techniques to provide sustainability	Case Study	+
(Pampanelli, et al., 2011)	The link between lean and sustainable operations	Case Study	+
(Yang, et al., 2011)	The effect of lean manufacturing and environmental management on job performance: an empirical study of manufacturing companies	Structural equation	+

Authors Name	Article Name	Type	Relation
(Pereira-Moliner, et al., 2012)	Quality management, environmental management and firm performance: direct and mediating effects in the hotel industry	Structural equation	+
(Wiengarten and Pagell, 2012)	The importance of quality management for the success of environmental management projects	Statistical Methods	+
(Diaz-Elsayed, et al., 2013)	Evaluation of lean and green strategies by simulating production systems in discrete production environments	Discrete simulation	+
(Govindan, et al., 2014)	The effect of supply chain management practices on sustainability	Structural equation	+
(Galeazzo, et al., 2014)	Lean and Green in Action: Interdependencies and Performance of Pollution Prevention Projects	Case Study	+
(De Sousa Jabbour, et al., 2014)	Quality management, environmental management maturity, green supply chain practices, and green performance	Structural equation	+
(Dubey, et al., 2015)	Examining the relationship between leadership, operational performance, institutional pressures, and environmental performance	Structural equation	+
(Campos et al., 2016)	Green and lean synergy in supply chain management	Case Study	+
(Resta, et al., 2017)	How lean manufacturing affects sustainable value creation: an integrated model	Deep Review	+/-
(Chang and Cheng, 2019)	Development analysis model of production sustainability of small and medium enterprises in Taiwan	Structural equation	+
(Qureshi, et al., 2019)	Modeling work practices under socio-technical systems for sustainable production performance	Structural equation	+

Based on the information in Table 2, the following can be concluded:

• in none of the studies the hidden relationships between the critical success factors of total quality management and environmental indicators have not been examined.

• Regarding the method, although some simulation methods have been used in a few studies, specifically, the systems dynamics method has not been used to simulate the relationship between total quality management and green production.

• By examining the table, it can be concluded that in drawing the causal-loop diagram of the study, positive feedback loops should be created between total quality management and environmental indicators.

3. Methodology

The case study of this research is a manufacturing organization in the field of the automotive industry in Shiraz. Considering that the structure of TQM has a cause-and-effect structure and, in addition to exogenous factors, it is influenced by endogenous factors and communication, the research method based on the SD approach was considered because by applying this method, a policy designed different policies and evaluated the results of each policy. As a quantitative-qualitative research approach, the system dynamic method aims to describe the problem dynamically to raise the level of learning in complex systems because the subject is revealed as a pattern of behavior over time. The main elements of the present research are the key factors of the success of total quality management and its results, and the purpose of the study is to create a framework for the evaluation and development of total quality management with a system dynamics approach. In system dynamics modeling, first, a picture of the relationships between the principal elements is presented, which is the basis of other modeling stages. The premise of the current research is that TQM is created from complex relationships between key success factors and their increasing influence on TQM results. Therefore, it was tried to identify the relations of the elements in the studied company using the fuzzy DEMATEL method, a tool for identifying the structure of relationships between related elements. This hybrid approach has been used in similar studies (Jafari et al., 2008; Khorakian and Salehi, 2015; Parchami and Shoar, 2017). Using the Fuzzy DEMATEL method makes it possible to use the attitude of experts to draw casual-loop diagrams. The final product of this method is to present network relationships between the elements of the issue and divide them into two causal and effectual groups. Therefore, with the help of this method, it is possible to systematically identify the factors affecting a cause, which have resulted from the factor extraction stage, based on the information from the judgment of experts, in a way that shows the direct and indirect relationships between them. (Chen et al., 2007). Although the DEMATEL method is suitable for evaluating problems, definitive data are insufficient. Human judgments in comparisons related to decision-making methods are primarily unclear, so they cannot be shown with precise numerical values. For this purpose, fuzzy logic was used (Lin and Wu, 2004). In this study, the steps of Garakhani's method were used for group DEMATEL (Gharakhani, 2012), and for defuzzification, the modified CFCS method (Opricovic and Tzeng, 2003) was used. Table 3 shows the final matrix of the DEMATEL method, based on which circular causal and the stock and flow diagrams of the system dynamics method are drawn. For this purpose, the threshold limit was considered the average of all matrix levels. Based on this, model variables affect the maturity level of total quality management in different ways and based on multiple feedback loops.

In the next step, the dynamic hypothesis of the research is defined as follows: TQM index (maturity level of total quality management) is the result of the total score of the key factors of success and results. Increasing the score of key success factors increases the score of results. On the one hand, increasing the score of the results reduces the gap between the desired results and the results' score and reduces the results' rate. Since the polarity of the result rate is positive with the score of the results, a negative feedback loop is created. On the other hand, increasing the score of results increases the rate of key success factors and their score because reducing the results gap makes TQM outputs more tangible, and more attention is paid to key success factors. Thus, a circle of positive feedback is created. Also, increasing the score of the critical success factors of TQM reduces the gap between the score of the key success factors and their desired level and the rate of the essential success factors. In this way, another negative circle is formed. In addition to these general loops, feedback loops resulting from the internal relationships of the key success factors of TQM are created. The causal diagram of the research dynamic hypothesis is shown in Figure 1.

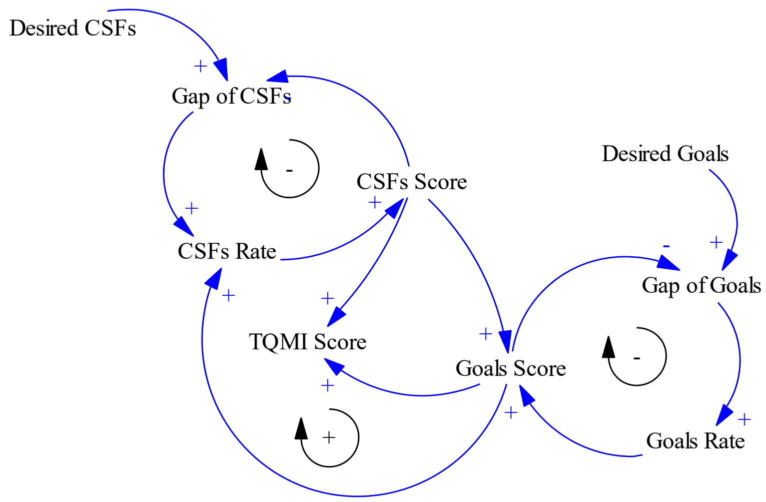


Figure 11. The dynamic hypothesis of the study

First, the score of the key factors of success in time (t): This score is obtained from the total score of each of the eleven key success factors, and it is maximum equal to 500. Second, the score of the objectives at the time (t): the score of the goals is obtained from the sum of the points of each of the five goals, and the maximum is equal to 500. Third, the total quality management index score in time (t): the maximum is equal to 1000, and it is the sum of the scores of key success factors and goals. Fourth is the desirable score of goals: the level every organization strives to achieve. In the present study, this score was calculated for each of the five results based on the opinions of experts and the network analysis method. Fifth, the goal gap at the time (t): is the difference between the desired score of the goals and the goal achieved at the time (t). Sixth, the rate of results in time (t): is a function of the results gap and the percentage of results improvement, which is a function of other variables affecting each outcome. The desired score of the critical success factors, their gap, and rate in time (t) are defined as their corresponding variables in the objectives.

Building mathematical relationships between all variables are complex (Parchami and Shoar, 2017), especially if the variables are linguistic and there is no documented data about them. To overcome this problem, Takagi-Sugno-Kang (TSK) fuzzy inference system method was used in this research. Collective fuzzy inference systems use fuzzy membership functions to receive inputs and use fuzzy rules instead of definite rules and zero or one to process and perform inference (Fasanghari and Montazer, 2010). The input includes vague and imprecise verbal concepts for a specific event, and the output contains a fuzzy or precise set of particular features. Based on this, the input and output sets are the research's input and output variables, and the researcher seeks to discover the relationships between them (Efendigil, et al., 2009). A TSK fuzzy system has the following components (Foong, et al., 2009):

1. An input fuzzifier converts the variables' numerical value into a fuzzy set. In the current research, fuzzy triangular numbers have been used to fuzzify model values.
2. Fuzzy rule base, a set of if-then rules, forms the main fuzzy inference system. A fuzzy rule can be considered in equations 1-2 (Takagi and Sugeno, 1993):

$$R_j : if\ x_1\ is\ A_{1j}\ and\ x_2\ is\ A_{2j}\ and ... and\ x_n\ is\ A_{nj}\ then\ y = g_j(x_1, x_2, ..., x_n)\ \ (j = 1, 2, ..., n) \tag{1}$$

In the above relationship, n is the number of input variables, R is the number of fuzzy rules, A_{ij} is the fuzzy set corresponding to the i_{th} input variable for the j_{th} fuzzy rule, and g_j is a constant function of x_i, which generally has a simple linear form as follows:

$$g_j(x_1, x_2, ..., x_n) = q_0 + q_1x_1 + ... + q_nx_n \tag{2}$$

All the present research rules have two, three, or four input variables, and all have one result or output. Experts have been used to determine the output of each rule. In this way, the opinions of seven experts were obtained with a questionnaire, and after integration with the CFCS method, the form of a non-fuzzy number was expressed.

A fuzzy inference engine transforms inputs into outputs with a series of actions. In the present study, Mamdani's requirement relation uses the Min operator. The final output of the above fuzzy system can be expressed in equation 3:

$$y = \frac{\sum_{j=1}^{R} g_j T_{i=1}^{m_j} \mu_{ij}\left(x_j\right)}{\sum_{j=1}^{R} T_{i=1}^{m_j} \mu_{ij}\left(x_j\right)} \tag{3}$$

Where μ_{ij} is the membership function for the fuzzy set A_{ij}, m_j is the number of input variables of the j_{th} fuzzy rule, and T is an operator.

3.1. The stock-flow model

In order to prepare the dynamic model for its simulation and implementation by the software, drawing the causal-loop diagram based on the results of the fuzzy DEMATEL method, these diagrams were converted into stock-flow diagrams to formulate the model. Here, the stock-flow diagram of variable patterning (*BE*) (Figure 2) is explained. According to Table 3, the value of this variable is a function of two variables (*TMCL*) and (*BSR*).

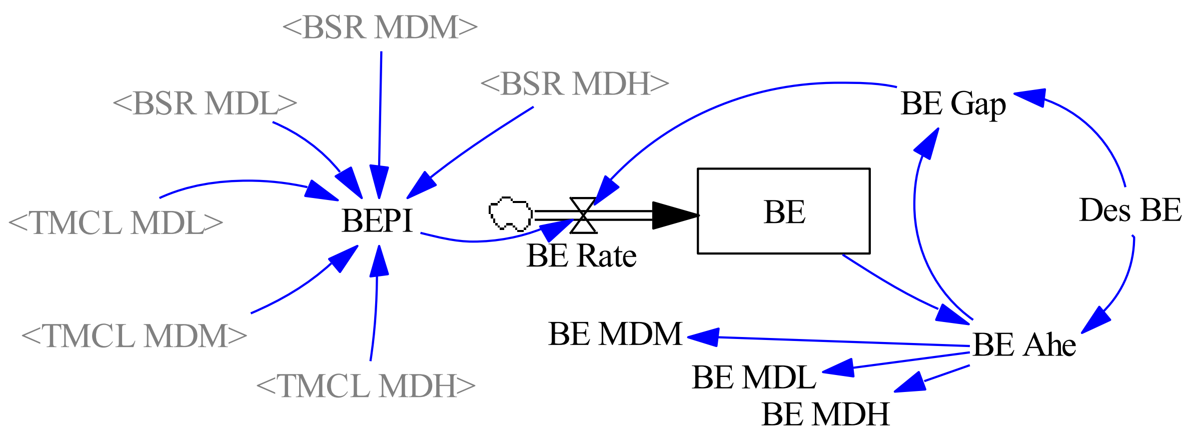


Figure 12. The sampling variable stock-flow diagram

As mentioned, the TSK fuzzy inference system has been used to determine the mathematical relationship between these variables. Accordingly, in this part, *TMCL* and *BSR* are input variables, and the *BEPI* variable is the output variable. The input variables are converted into fuzzy numbers based on the triangular fuzzifier function. For example, *TMCL MDL* is the degree of membership of the *TMCL* variable to the low state value. The following function shows how to calculate the *BEPI* variable based on the *TSK* method.

$$
\begin{aligned}
BEPI = {} & (((MIN(TMCL\ MDL, BSR\ MDL) * 0.041) + (MIN(TMCL\ MDL, BSR\ MDM) * 0.457) \\
& + (MIN(TMCL\ MDL, BSR\ MDH) * 0.785) + (MIN(TMCL\ MDM, BSR\ MDL) * 0.452) \\
& + (MIN(TMCL\ MDM, BSR\ MDM) * 0.67) + (MIN(TMCL\ MDM, BSR\ MDH) * 0.88) \\
& + (MIN(TMCL\ MDH, BSR\ MDL) * 0.458) + (MIN(TMCL\ MDH, BSR\ MDM) * 0.7) \\
& + (MIN(TMCL\ MDH, BSR\ MDH) * 0.95)) / (MIN(TMCL\ MDL, BSR\ MDL) \\
& + MIN(TMCL\ MDL, BSR\ MDM) + MIN(TMCL\ MDL, BSR\ MDH) \\
& + MIN(TMCL\ MDM, BSR\ MDL) + MIN(TMCL\ MDM, BSR\ MDM) \\
& + MIN(TMCL\ MDM, BSR\ MDH) + MIN(TMCL\ MDH, BSR\ MDL) \\
& + MIN(TMCL\ MDH, BSR\ MDM) + MIN(TMCL\ MDH, BSR\ MDH)))
\end{aligned}
$$

The number of fuzzy rules required to specify the relationships between variables is a function of the number of inputs, and since we have two inputs here, nine rules have been written. In general, if the number of inputs of a fuzzy system is n and the number of membership functions for each input is m, m^n, the fuzzy rule is created. Accordingly, with the increase in the number of input variables, the number of rules of fuzzy systems will grow exponentially. A proposed solution to overcome this problem is to create hierarchical fuzzy systems based on creating multiple fuzzy systems with small dimensions (Brown et al., 1995; Chen and Linkens, 2001).

Due to the complexity of the investigated problem, the stock-flow diagram was presented in three parts, which are related to each other through shadow variables.

It should be noted that to avoid more complexity of stock-flow diagrams, these diagrams are drawn in a deterministic state. It should be noted that according to the research method for formulating the model of each of the input variables of the rate variables as well as auxiliary variables resulting from the design of the fuzzy inference system, as in Figure 3, it is first converted into fuzzy numbers based on the triangular fuzzifier function. And then, the corresponding equations are written. Figure 3 shows the stock-flow diagram of the key success factors of total quality management.

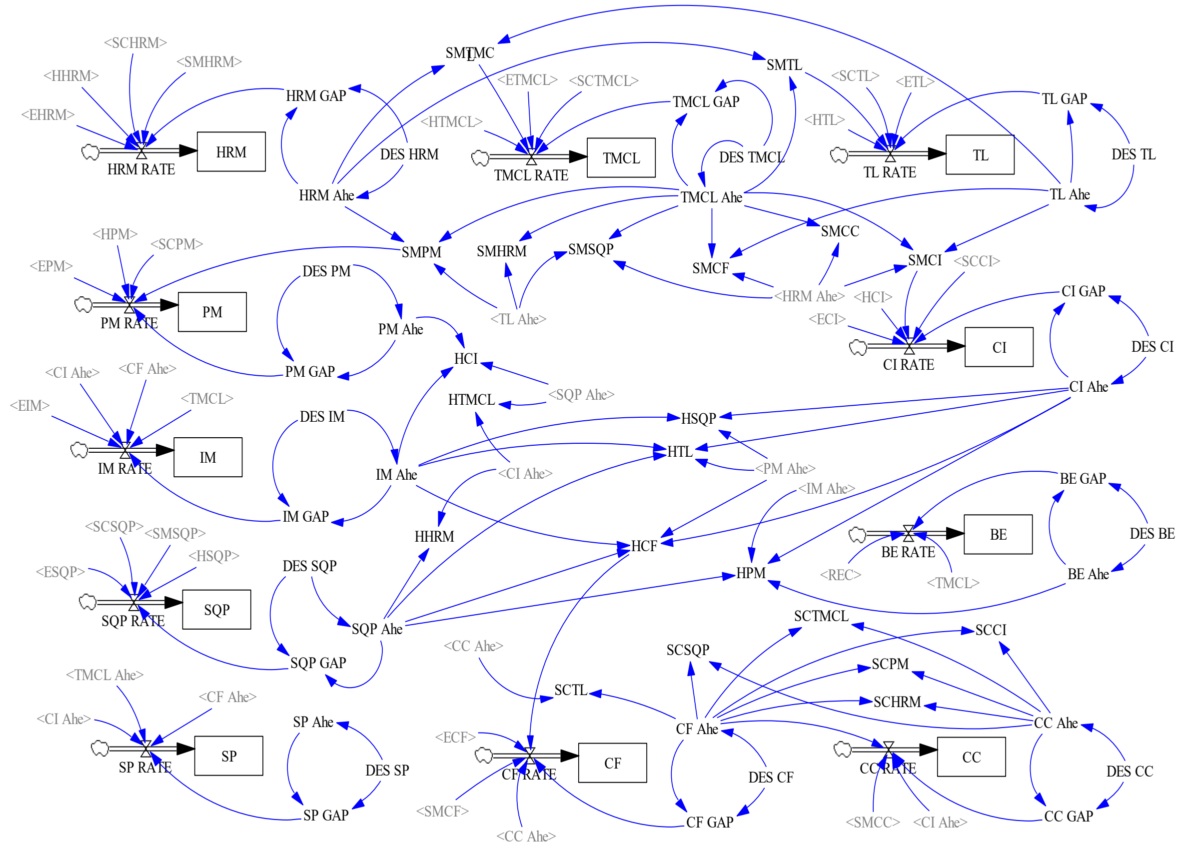


Figure 13. The stock-flow diagram of the key success factors of total quality management

Figure 4 shows the stock-flow diagram of environmental indicators.

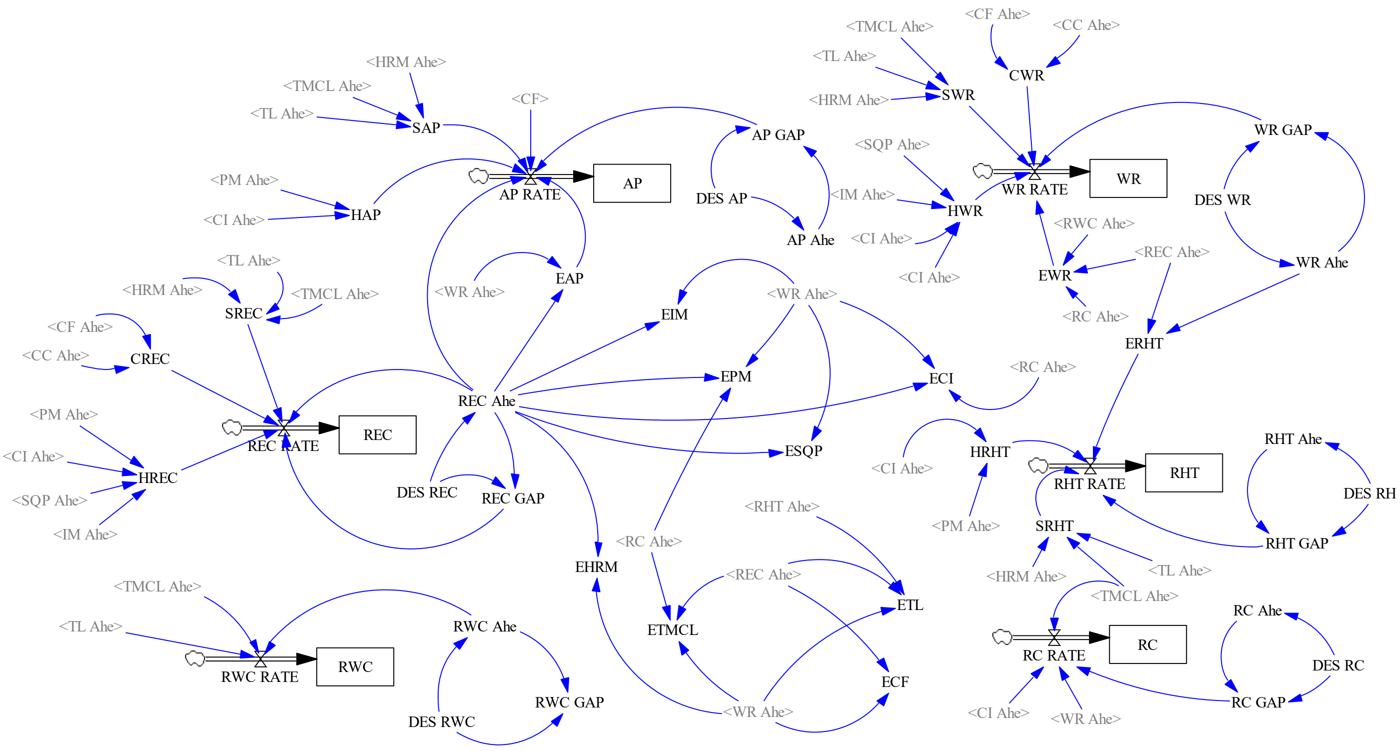


Figure 14. The calculation of the environmental index

Finally, the environmental index was calculated based on Figure 5.

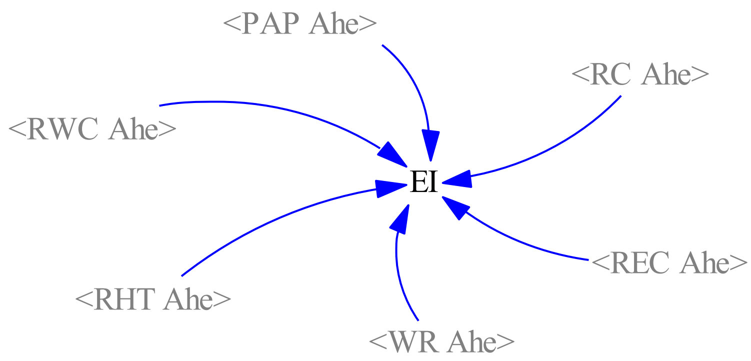
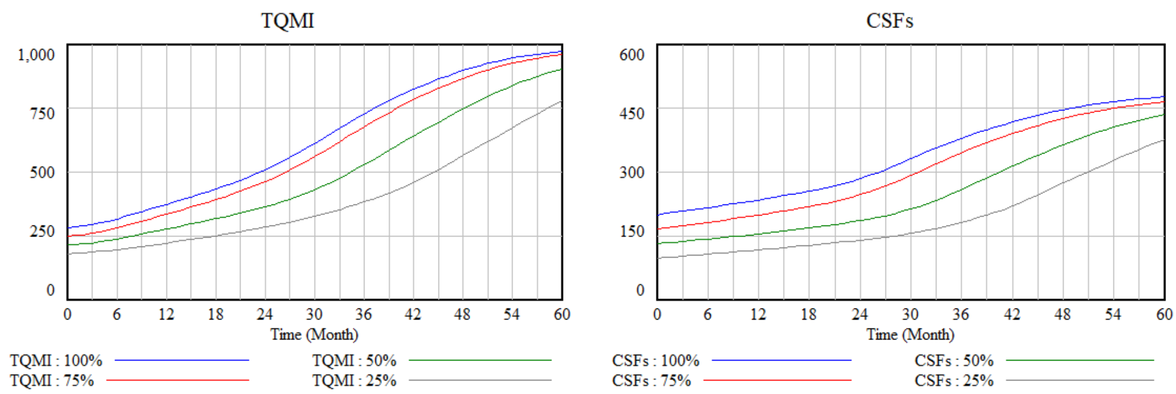


Figure 15. The calculation of the environmental index

4. The model simulation and validation

After formulating a simulation model, testing the model begins. Validation of any system dynamics model is necessary to ensure the validity of its results in the context of the organization under study (Khanna et al., 2003). In the current research, the validation of the model has been investigated in two parts, conceptual and software testing. Identifying key success factors and TQM results based on research literature review and identifying relationships between them based on experts' opinions and using DEMATEL's method guarantees the model's validity from a conceptual point of view. In the software testing section, two forms of behavior sensitivity and repeated behavior testing have been used. The test of sensitivity analysis or limit behavior is performed to check the model's adaptability in response to the changes made in a model. Here, the sensitivity analysis of the model was done by changing the initial value of the TMCL variable (values of 25, 50, 75, and 100 percent of the maximum score).



a: sensitivity analysis TQML b: sensitivity analysis CSFs

Figure 16. The results of sensitivity analysis in case of changing the initial value of TMCL

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As the simulation results show, the change in the initial value of the TMCL variable has only affected the model's behavior from the numerical aspect and has not affected the model pattern (Figure 6). This issue indicates the validity of the model. Repeating this issue for other variables also leads to the same result.

The purpose of retesting is to compare simulation results with accurate data. In other words, in this case, the simulated behavior is reproduced for the model to be compared with the actual data. In this study, experts were asked about the status of system variables in the past year to perform this test, and the model was run with this information. The model's answers were compared with the solutions of experts regarding the number of variables in the current situation. This method has been used to evaluate the validity of systems dynamics in similar studies (Khanna et al., 2003). The results are shown in Table 3. As it is known, the results confirm the validity of the model.

Table 12. The values of enablers and results based on experts' opinions and software output

TQM variables	Results based on		Deviation percentage
	System dynamics model	Expert opinions	
TMCL	30.475	28.9832	0.051
HRM	15.751	16.7821	-0.061
TL	10.497	9.1965	0.141
CF	9.12	10.129	-0.099
SP	0.6841	0.6102	0.1211
CC	3.1481	3.676	0.143
PM	1.975	2.145	-0.079
IM	4.1423	4.356	-0.049
SQP	4.875	5.2145	-0.065
BE	0.467	0.6478	-0.001
CI	13.287	11.91	0.115

Also, the limit behavior method has been used in the software testing section. In the limit condition test, conditions are considered in the model that may not be seen in the real world, and then the model's behavior is compared with the standard requirements. In the present model, the input rate of the state variables was examined to fulfill the limit conditions. In one case, all inputs were considered equal to zero. The behavior of the EI variable in this situation is shown in figure 7.

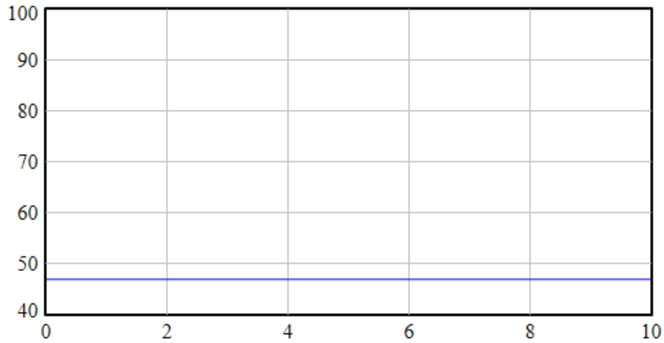
Figure 17. The behavior of the EI variable in the limit condition of zeroing the input rate of the state variables

When the input rate of all state variables is considered equal to zero, the amount of variable index EI remains constant and does not change. Since the model's assumption was based on maintaining and improving the current condition, the model's behavior in these limiting conditions is consistent with the expected behavior. In the next step of the limit condition test, the input rate of the state variables was increased ten thousand times to measure the model's response. You can see the behavior of the EI variable in this situation in Figure 8.

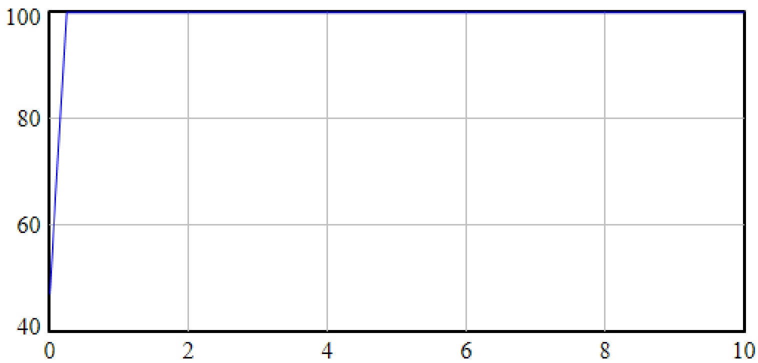
Figure 18. The behavior of the EI variable, in the limit condition of ten thousand times the input rate of state variables

Then, to identify the price policy for the evolution of comprehensive quality management to improve environmental indicators, three policies were defined as follows:

- The first policy: paying more attention to soft management factors by 25%
- The second policy: pay more attention to soft communication factors by 25%
- The third policy: paying more attention to hard factors by 25%

The simulation results are shown in Figure 9.

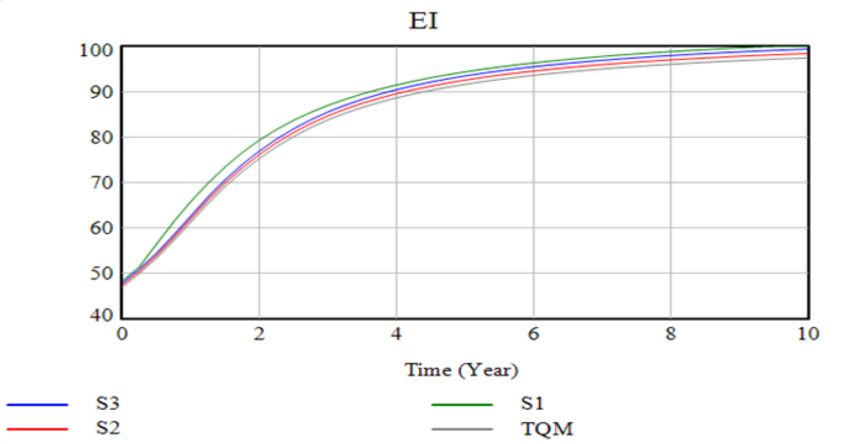

Figure 19. Simulation results of study policies

As the graph shows, although all the policies lead to the improvement of the environmental indicators, the acceleration of this improvement is far more significant with the implementation of the first policy; after this, there are the third and second policies. Another noteworthy point is that in the first months of the policy's implementation, the environmental indicators' improvement process is tangible compared to the normal state, but this is not the case with the other two policies. With the passage of nearly two years, this improvement process can be understood compared to the normal state. Did the results clearly show that applying the first policy means paying more attention to soft management factors leads to better outcomes?

5. Discussion and conclusion

In recent years, the green economy has been proposed as an emerging concept with the aim of sustainable development (Diekola, 2016). Environmental quality is a general term that can refer to various characteristics related to the natural environment as well as the built environment, such as the purity of air and water or noise pollution and the potential effects that may have on physical and mental health (Diekola, 2016), on the other hand, in production environments, the implementation of lean production and the elimination of all activities without added value has been considered. Lean and green production have common goals and can help each other in the implementation process. Lean production has several techniques, each requiring significant investment and costs (Tisch et al.,2019). The present study was conducted to identify the best policy in applying attention to the comprehensive quality management technique to improve environmental indicators in a production environment. The study aimed to help the organization in choosing the best policy by simulating it because the inappropriate use of lean production techniques increases the inefficiency in the use of the organization's resources and, as a result, increases the waste, cost, and time of production and also reduces the trust of employees in the strategy. (Amin and Karim, 2013; Marvel and Standridge, 2009).

The results show a strong relationship between total quality management and environmentally friendly production systems. According to a study in Chinese manufacturing industries, TQM, directly and indirectly, affects environmental sustainability (Green et al., 2019). Weingarten and Pagel (2012) showed that implementing quality management methods such as comprehensive quality management can lead to implementing environmental management methods such as pollution prevention, material recycling, and waste reduction. Resta et al. (2017) showed that comprehensive quality management negatively affects the environment due to increased energy consumption.

Based on the research findings, it can be said that the overall effect of more efforts to improve the soft factors of comprehensive quality management is more significant on the improvement of environmental indicators. Based on the study's results, it is suggested to the manufacturing company that the top management increases its support in various ways, such as allocating funds for comprehensive quality management, spiritual and organizational support for quality, and launching the company's quality award. It is also suggested to assess educational needs, set up academic courses, and evaluate their effectiveness in teaching and learning.

The present research has limitations. The weight of the experts from whom the data was obtained in various stages of the study has been considered the same without considering their differences. In contrast, in practice, the knowledge and experience of the experts are different, and it is necessary to account for these differences in the allocation. Weight should be given to them. Another limitation of the current model is not introducing a delay in the problem modeling process and the assumption of maintaining the current conditions and trying to improve the system variables. Finally, the present research was conducted in a production organization and is cross-sectional in terms of time, so one should be careful in generalizing the results. The hybrid model of the present research only deals with subjective uncertainty. Hence, it is suggested to expand the current model to respond to possible delays simultaneously. Future research can also apply machine learning techniques, such as data-driven fuzzy rule-based systems (FRBS), artificial neural networks (ANN), fuzzy neural networks, and fuzzy neural systems, to define relationships between system variables in Dynamic fuzzy models of the system automatically from the data. Communicating with relevant software such as MATLAB and EniLogic can help researchers in this field. Also, considering that increasing the number of fuzzy inference system rules makes data collection and analysis difficult, it is suggested to use other methods to reduce the number of inference system rules.

Disclosure statement

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

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An Analysis of Influential Factors on Procurement Cycle Time Using a System Dynamics Approach

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ABSTRACT

Organizational agility is one approach that allows organizations to rapidly adapt to these conditions, which can be extended to the agility of individual business processes within the organization. Procurement cycle time is one of the most critical performance indicators that measure procurement process agility. This study will study the factors impacting procurement cycle time using a system dynamics modelling approach. To achieve this, the subsystems are defined and modelled, including internal subsystems like production and sales processes and external ones like market and suppliers. Next, the interactions of these subsystems are analysed, and the casual loops and stock-flow model of the problem are analysed and developed. The model has been implemented and validated in a production organization under the seasonal demand factor. Finally, three policies were proposed to reduce the procurement cycle time, and the simulation results of the policies were analysed numerically. According to the obtained results, combining the presented policies will lead to a 22% reduction in the procurement cycle time.

Keywords

Business process management, Supply chain management, System dynamics, Procurement cycle Time, Organizational agility.

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1. Introduction

New technological developments, shortening of product life cycles, diverse customer needs and increasing demand for a variety of products in the current global markets have greatly reduced the predictability of the market and exacerbated the uncertainty. According to these conditions, firms should have the necessary flexibility and agility to adapt to the socio-economic changes of the market so that they can maintain their competitive advantage (Almahamid, et al., 2010). Different definitions of organizational agility have been presented in the literature. These definitions include "the ability of a system to quickly respond to changes while maintaining the initial stability of the system" (Leybourn, 2013), "the ability to face unexpected challenges, deal with the risks of the business environment and use Changes as an opportunity" (Zhang and Sharifi, 2000) or "responding to customers and managing market changes" (Van Hoek, et al., 2001).

In addition, the increasing growth of firms and becoming more specialized has increased their need for goods and services outside the firm. In this regard, the procurement unit in every firm is responsible for meeting these needs from external sources; As a result, the increase in the firm's profit margin is dependent on the performance of the procurement unit through the rise in the ratio of the value to the price of the supplied goods and services (Pereira et al., 2014). An agile firm also needs an agile procurement process; Because this process has the task of supporting all the firm's operations. The procurement process helps the firm's agility by providing goods and services based on customer demand, quickly adapting to business environment changes, and using new solutions and resources (Nicoletti, 2018).

The main goal of agile procurement is to design and use a process that can plan capacity and coordinate the implementation of the procurement process. Riley and Brooks (2012) state the necessary factors for the agility of the procurement process as follows:

(1) Transparency of the whole process and having information about customers, suppliers and orders
(2) Increasing interaction between procurement and other departments, including customers and suppliers
(3) Control levers include hard levers, such as the use of organizational power (management pressure) and soft levers, such as organizational culture and training

Moreover, Chiang et al. (2012) listed the factors affecting the agility of the procurement process: 1- the level of response to requests (procurement cycle time) and 2- the degree of flexibility of the procurement process against the market changes).

Since the procurement cycle time is easier to quantify, it was chosen to investigate the agility factor of procurement. If the procurement cycle time increases, the number of

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production stoppages due to the lack of required materials and services increases. As a result, the firm is unable to fulfil its agreements with its customers, leading to the loss of credibility of the firm and its customers. This study will examine and predict the firm's agility using systems dynamics methodology. In order to increase agility, certain policies are designed and tested upon the discovered model.

In order to quantitatively investigate the problem, the data of a stationery production firm has been studied. The graph of the changes in the procurement cycle time in this firm in the investigated period is shown in Figure 1. As can be seen in this graph, the procurement cycle time has experienced almost 100% growth compared to the initial periods. Considering that the seasonal demand factor increases in periods 4 to 8 in the investigated problem, this issue increases the procurement cycle time in two ways. First, with the increase in demand for the firm's products, the number of goods requested for purchase has increased, leading to an increase in the procurement cycle time. Second, since this factor increases the supplier's demand, and on the other hand, each supplier has a limited capacity to prepare orders, therefore, with the increase in the requested goods, the procurement cycle time also increases.

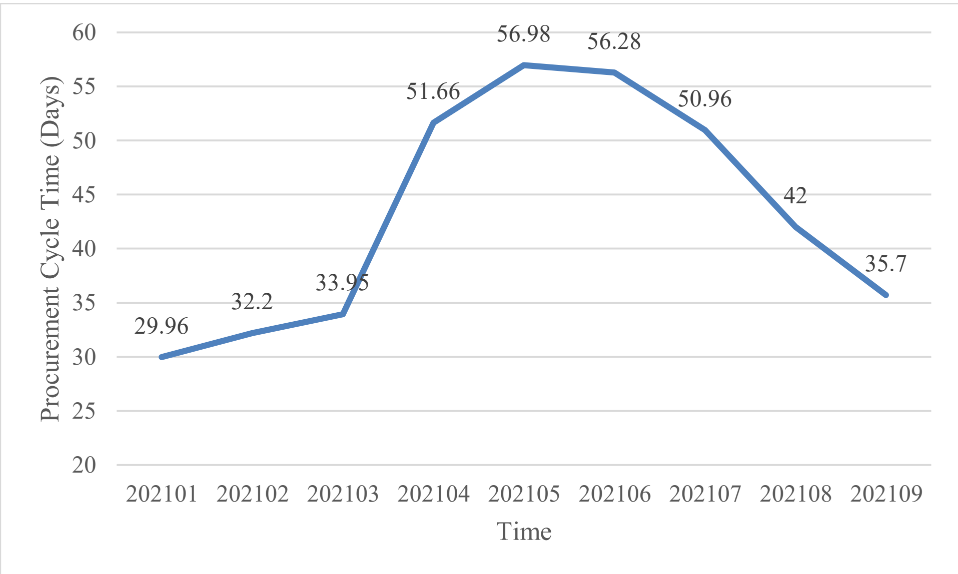

Figure 20. Diagram of changes in the procurement cycle time in the last 9 months of 2019

This paper is organized as follows. Section 2 reviews the related studies that have been carried out, section 3 presents the research methodology, in section 4 the problem would be modelled and validated based on case study historical data and also the model behaviour, and section 5 discuss and analyse the test results of designed policies and section 6 concludes on the presented model and obtained results.

2. Literature review

Ng et al. have identified three influencing factors on procurement cycle time. The first factor is the evaluation of suppliers. It means choosing a supplier who will send the ordered product quickly (Ng, et al., 1997). The next factor is the time of the procurement process itself within the firm. That is when a purchase requisition leads to a purchase order. The third factor is the firm-supplier relationship. This is because through the contract with the supplier, inspections can be done at the customer's site, and the inspection time can be reduced. In addition, inventory information can be shared so that when the order point is reached, the supplier can send the orders without going through the procurement process. Swafford et al. (2006) define the flexibility of the procurement process as the availability of different options when purchasing and the ability of the procurement process to change the selected options when needed. The meaning of these options is the ability to influence the procurement time and the supplier's capacity assigned to the firm. Firms with more suppliers have more options and a stronger bargaining position.

Abolbashari et al. (2018) have presented a dynamic model for measuring, managing and predicting procurement performance. They have considered influencing factors inside and outside the firm as subsystems of the problem. Besides, they used a concept called the “smart buyer”, which can measure purchase performance, manage purchase performance, and predict purchase performance. To study the performance of the procurement process, they used key performance indicators based on experts' opinions in the field as variables of the model and finally validated the model. Sawan et al. (2018) have developed a dynamic model to understand the factors influencing the cost of quality in the procurement of building materials using the traditional method of prevention/evaluation/failure. This model aims to identify opportunities to reduce quality costs without lowering quality. They have considered three subsystems of prevention costs, evaluation costs and failure costs in their model. Using the data of an operational project, the authors have simulated the model and analysed its results to evaluate different quality assurance policies. Barrad et al. (2018) have proposed a dynamic model to save costs through sustainable measures in the procurement process. They have investigated the impact of procurement manpower and their training on the number of strategic and sustainable contracts with suppliers and the performance of the procurement unit.

Cedillo-Campos and Sánchez-Ramírez (2013) have proposed a model to investigate supply chain logistics performance in an emerging competitive market by considering key performance indicators as dynamic variables. This article investigates three subsystems of procurement, distribution and production, and the presented model is implemented in an example in the automotive industry. Finally, they have validated their model through the method of design of experiments (DOE) and using the data of their case study. Chen and Tan (2020) have presented a model for the procurement process in the construction industry. In this model, three subsystems of material inventory, cost and project schedule have been examined. Finally, they simulated the presented model. According to the observed problems and the two variables of the average inventory turnover and time required for purchasing materials in advance, three strategies have been considered to solve these problems.

According to the literature above, system dynamics approaches have not been used enough to model the factors affecting procurement cycle times. As a result, this study attempts to simulate the procurement cycle time by examining the influential factors and quantitatively analysing the simulation model.

3. Methodology

Different methodologies have been introduced to qualitative model factors using system dynamics. Luna-Reyes and Andersen (2003) conducted a systematic literature review on these methodologies. There could be different stages of modelling a problem using a system dynamic approach, e.g., Sterman (2002) viewed the modelling steps as problem definition, dynamic hypothesis, formulation, testing, policy information and evaluation. This research has implemented the last methodology. To be more precise, in this research, first, the problem is described, and the variables affecting procurement cycle time are identified. Second, the influence of chosen variables on each other is analyzed and modeled using causal loop diagrams (CLD). Using The concept of CLD can help to better analyze and understand the problem, e.g., one can refer to (Kiani *et al.*, 2009; Hosseini and Hosseini, 2022). Third, the extracted simulation model is tested upon a real data set obtained from the case study. Fourth, three improvement policies are designed, and the procurement cycle time behavior is probed under these policies.

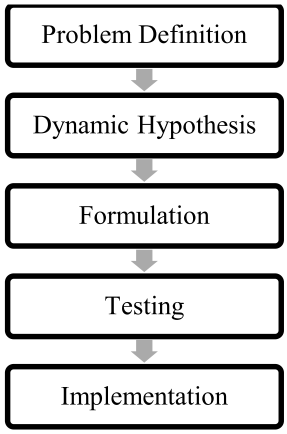

Figure 21. Research steps (Sterman,2002)

Figure 21 depicts the steps of described research methodology. It is to be mentioned that the case study data belongs to a stationery manufacturing company which is highly affected by seasonal demand, e.g., when the schools reopen in autumn, the demand for this product would boost significantly. It is to be noted that the dynamic assumptions of this research are developed based on current literature and also surveying the subject matter experts.

4. Problem definition

Here, we define our problem in a production firm. A manufacturing company's main value is created by selling manufactured goods (Terjesen et al., 2011). To that end, we have surveyed experts of the case study organization to obtain the current system status. In this case study, the sales department estimates the market demand through communication with customers and market studies or by receiving customer orders and preparing the sales plan. This plan is communicated to the planning department, and production commences on the production plan. On the other hand, the planning department registers the purchase requisition according to the inventory of raw materials and the production schedule. After reviewing the purchase requests, the procurement unit selects the appropriate supplier and registers the purchase order. After that, the supplier supplies ordered goods based on the internal capacity and the order of other customers and supplied goods are added to the inventory.

As seen in Figure 3, the procurement cycle time includes two parts: the time of converting a purchase request to a purchase order (the time of the internal procurement process) and the time of sending the goods by the supplier. The factor that affects the time of the internal procurement process is the type of transactions based on the transaction regulations. The classification that can be done in this case is the division of transactions into minor transactions and major transactions.

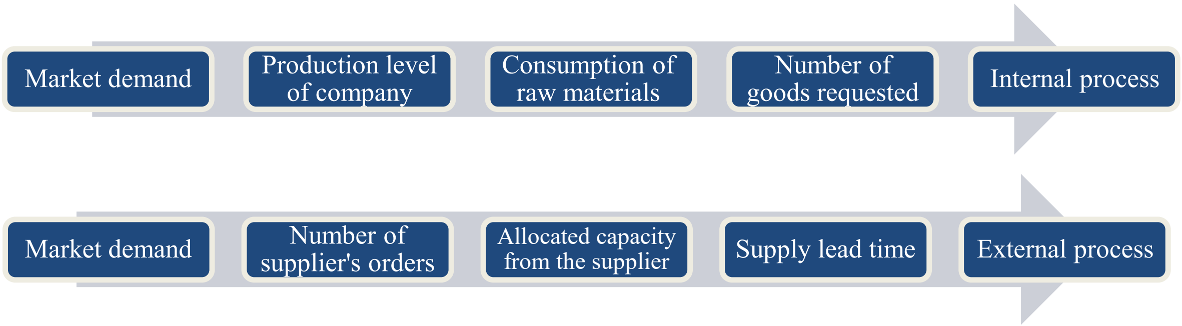

Figure 22. Overview of the problem

According to the procedure that must be done in order to carry out major transactions, the time of these transactions is longer than minor transactions. As the number of requested goods increases, the value of transactions increases and the possibility of being included in major transactions increases, and as a result, the time of the internal procurement process increases. On the other hand, with the increase in material consumption, the number of requested goods increases. With the increase in demand, the volume of production and operations of the firm will increase, which will cause an increase in the amount of material consumption. Another factor that affects the delivery time of the order from the supplier is the capacity allocated to supply the order. If the orders of other customers of the supplier increase, the supplier will allocate less capacity to the firm's order. As the market demand for the supplier's products increases, the orders of other customers also increase. Figure 4 shows the subsystems of the problem.

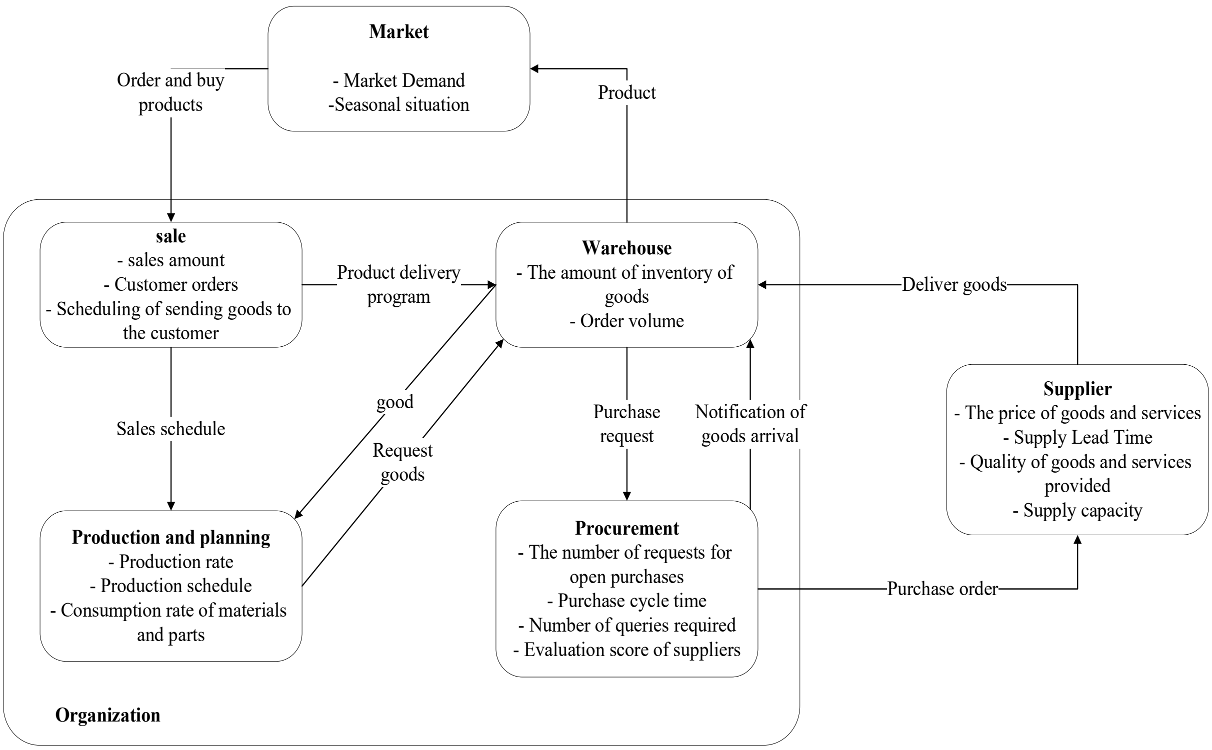

Figure 23. Subsystems of the case study

5. Modelling, review and analysis of data

5.1. Casual loops

The following are the causal loops of product inventory, procurement and supplier. As mentioned in section 4, the sales department estimates the market demand through communication with customers and market studies or formulates a sales schedule by receiving customer orders. As a result, with the increase in market demand, the firm's number of sales (planned and unplanned sales) also increases. The production schedule is a function of the firm's product inventory and the number of sales. As the production plan increases, the volume of production and operations of the firm increases, and as a result, the inventory of the firm's products also increases. On the other hand, with the increase in production, the consumption rate of raw materials for product production increases. As a result, the inventory level of raw materials decreases. With the decrease in raw material inventory level, the amount of product production also decreases. (Poles, 2013) presented a dynamic model of product inventory, which Figure 5 is an adaptation of this model.

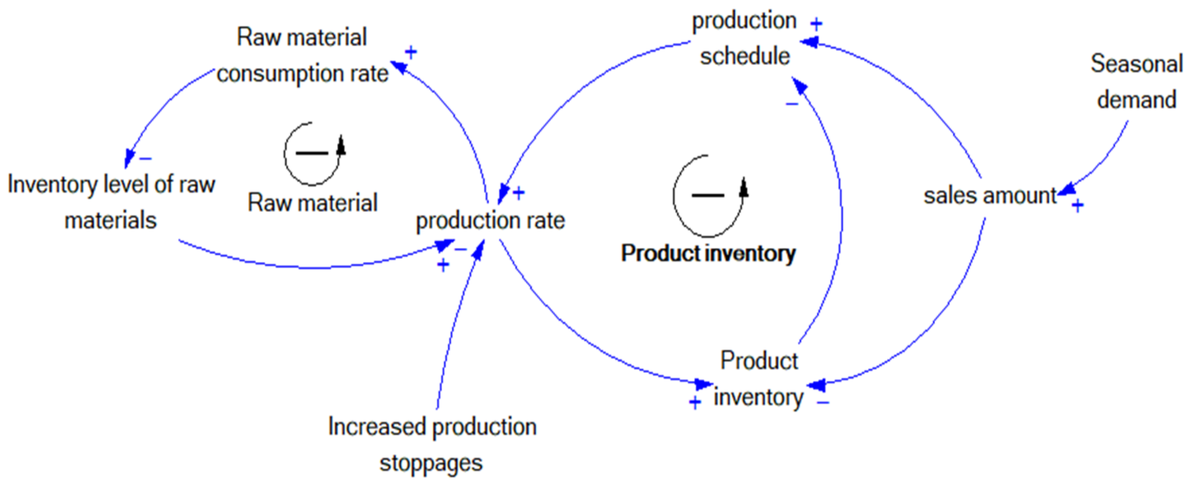

Figure 24. Structure of product and raw material inventory loop

With the increase in the number of items requested, the number of items in the order queue to be checked by the procurement expert increases and as a result, due to the price of raw materials, the time of the internal procurement process also increases. Also, as the time of the internal procurement process increases, the number of goods in the order queue is ordered with a greater delay. These ordered goods are added to the goods in the supplier's processing queue. As a result, due to the capacity of the supplier, it increases the time of supplying the order from the supplier. The longer the order supply time is, the more the number of products in the supplier's processing queue will be supplied with a greater delay. The supplied goods are added to the inventory of raw materials, which decreases and increases the requested goods.

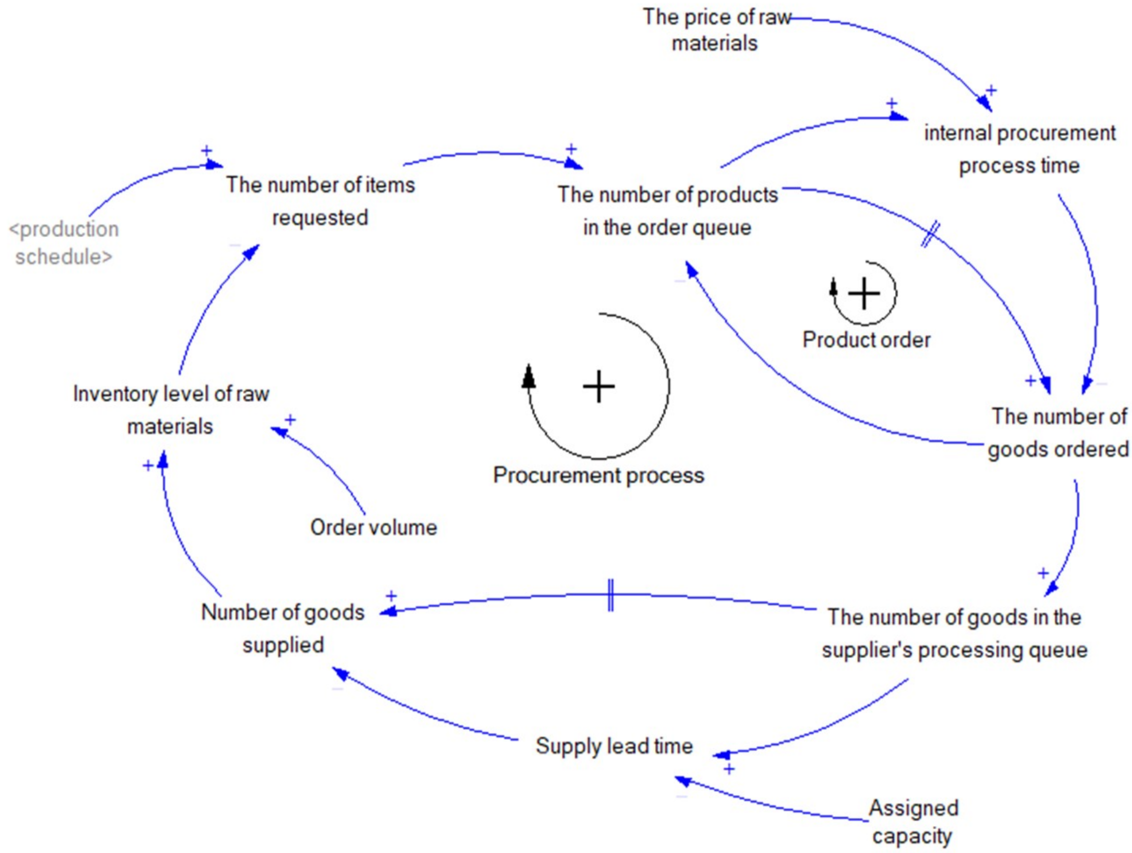

Figure 25. Structure of procurement process loop

As has been mentioned, one factor that affects the order supply time is the capacity that the supplier has allocated to our firm, which is affected by the supplier's total capacity and the orders of other customers. On the other hand, seasonal demand is a factor that affects the demand of other customers as well (Rafiei, et al., 2014). With the increase in the order supply time and the time of the internal procurement process, the procurement cycle time increases, which will lead to irreparable stops (Figure 7). As a result, the amount of production will decrease as depicted in Figure 6. Figures 5 and 6 were inspired by (Abolbashari, et al., 2018) and modified according to the conditions of the case study.

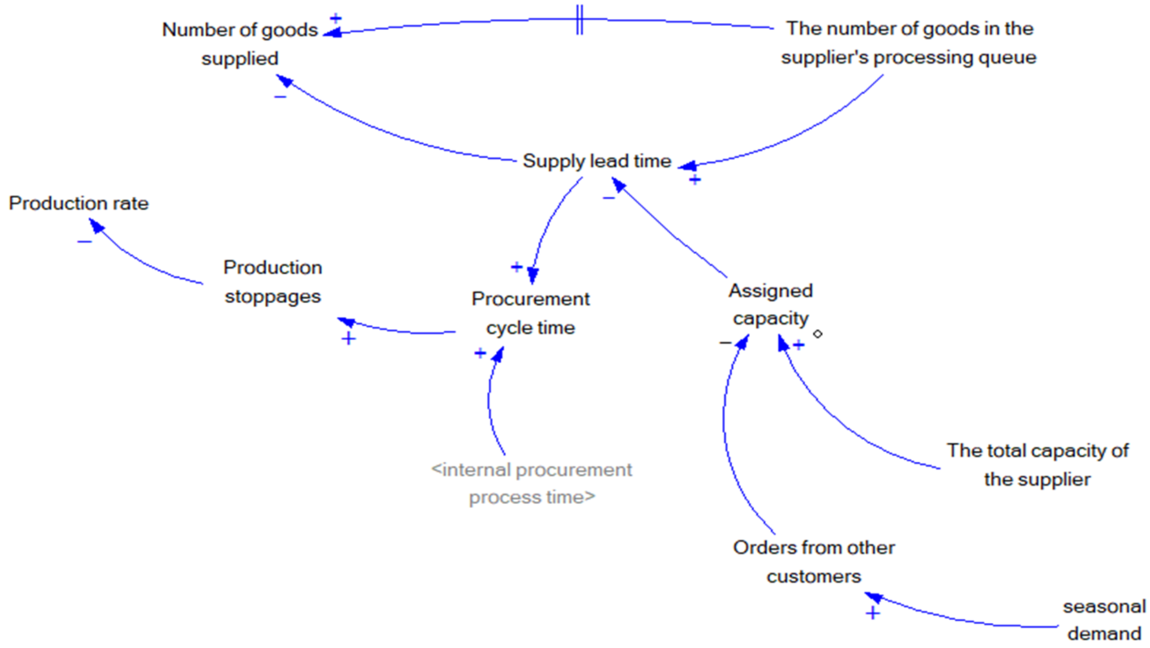

Figure 26. Factors affecting the procurement cycle time

5.2. Stock-flow diagram

The Stock -flow diagram of the problem is described in Figure 8. In this model, we have assumed that the desired product is produced from two raw materials with a constant consumption factor. Four types of stock variables are considered in equations 1-6:

(1) The number of goods in the order queue from raw material i ($NGOQ_i$)

(2) The number of goods in the supplier's processing queue from raw material i ($NGPQ_i$)

(3) Inventory of raw material i (RI_i)

(4) Product inventory produced by the firm (PI)

$$NGOQ_i = \begin{cases} NGR_i - NGO_i & if\ NGR_i \geq NGO_i \\ 0 & else \end{cases} \tag{1}$$

$$NGPQ_i = \begin{cases} NGO_i - NGS_i & if\ NGS_i \leq NGO_i \\ 0 & else \end{cases} \tag{2}$$

$$RI_i = \begin{cases} NGS_i - CC^{2}{}_i * P^{3} & if\ CC_i * P \leq NGS_i \\ 0 & else \end{cases} \tag{3}$$

$$PI = P - S^{4} \tag{4}$$

$$NGO_i = DELAYFIXED(NGOQ_i, IPCT^{5}, 0) \tag{5}$$

$$PCT^{6} = IPCT + SLT^{7} \tag{6}$$

[2] Consumption Coefficient of raw material i used in final product
[3] Production
[4] Sales
[5] Internal Procurement Cycle Time
[6] Procurement Cycle Time
[7] Supplier Lead Time

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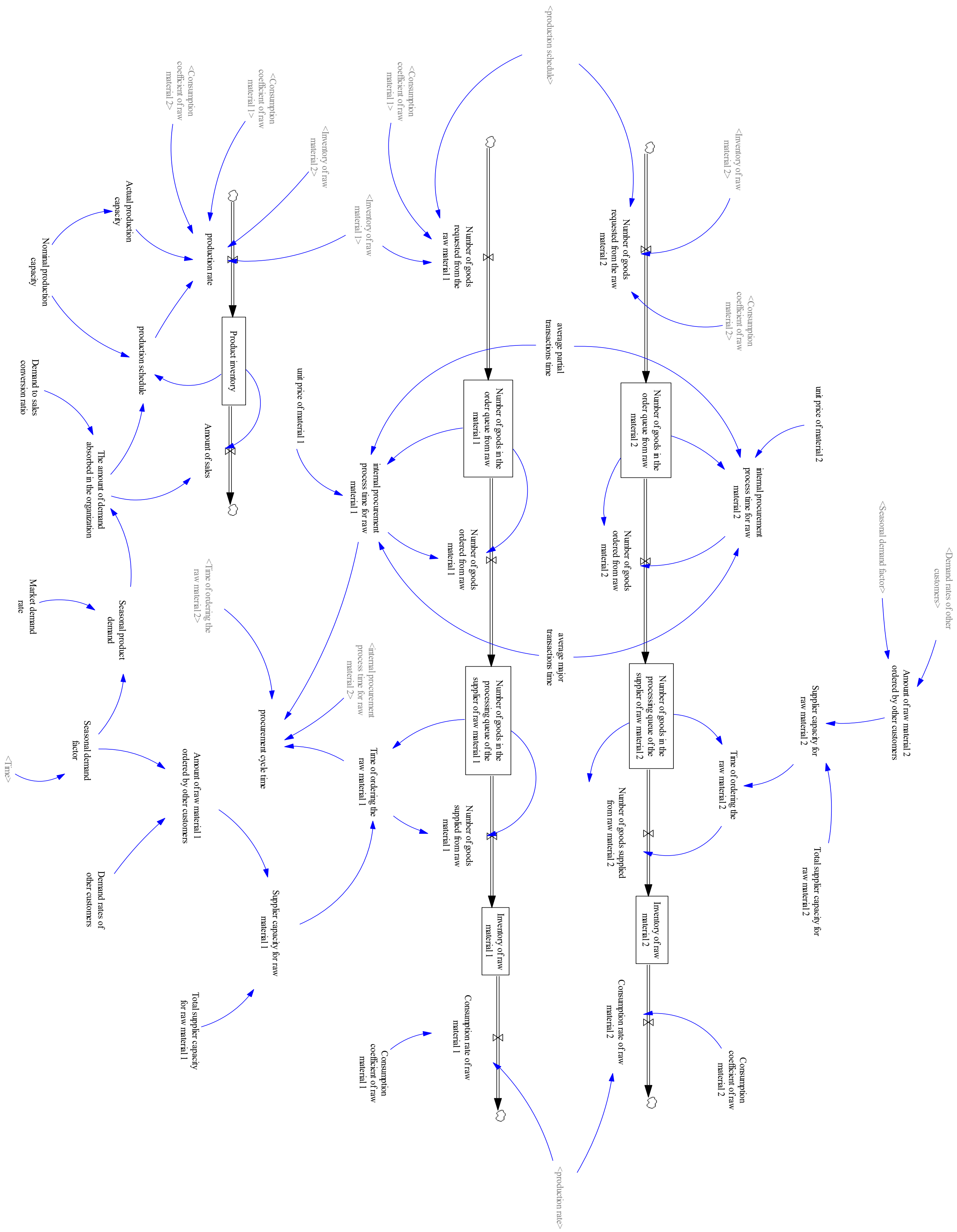

Figure 27. Stock-flow diagram of the procurement cycle time

5.3. Validation

System dynamics models are always built with a specific goal in mind. Therefore, it is not possible to say that the model is correct or incorrect, but its validity can be examined continuously.

5.3.1. Behavior reproduction test

The effects of formulas and equations are compared to the real system for this test. The graphs obtained from the model made by Vensim are compared with the graphs obtained from historical data. Next, the diagram related to this test for the procurement cycle time is given in Figure 9.

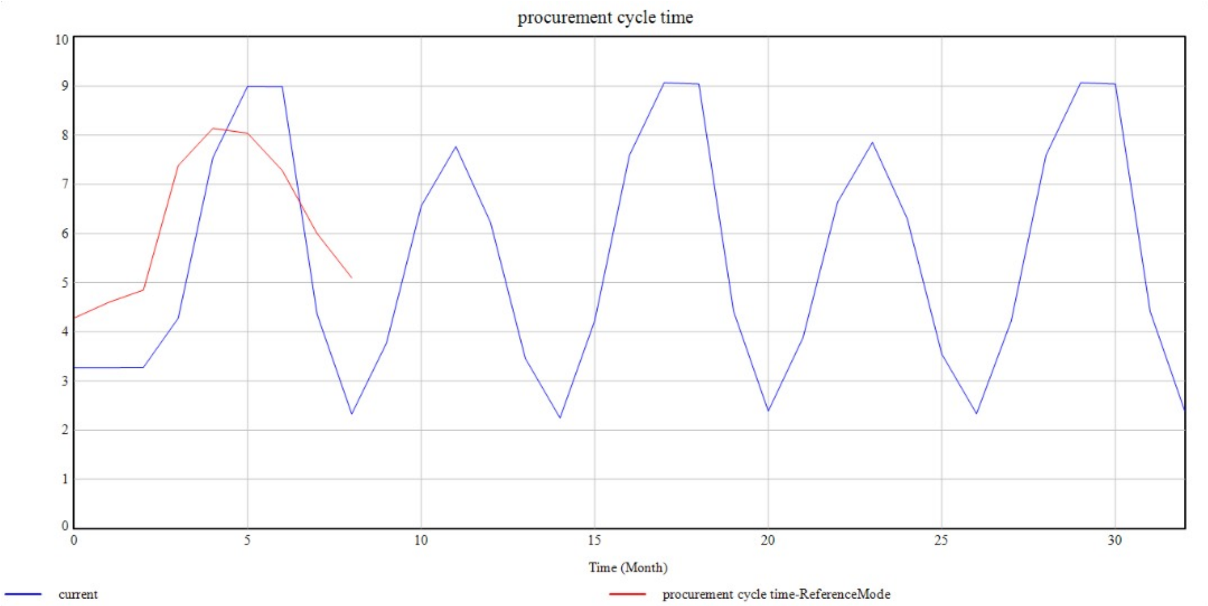

Figure 28. The first validation test (procurement cycle time)

As shown in Figure 9, the model's behaviour in the first 6 months of the simulation time is the same as the behaviour of the reference diagram. In this way, in the last quarter of the year, considering that the seasonal demand increases, the amount of production increases, and as a result, the purchase cycle also increases at that time. In the first quarter of the year, because the seasonal demand is less, the time of the purchase cycle is also downward, and this behaviour can also be seen in the graph.

5.3.2. Extreme condition test

In this test, to check whether the dynamics of the model work in different situations, the conditions and formulas of a number of variables are changed, and the results are examined.

According to Figure 10, the procurement cycle time behaviour will be affected if the nominal production capacity increases or decreases.

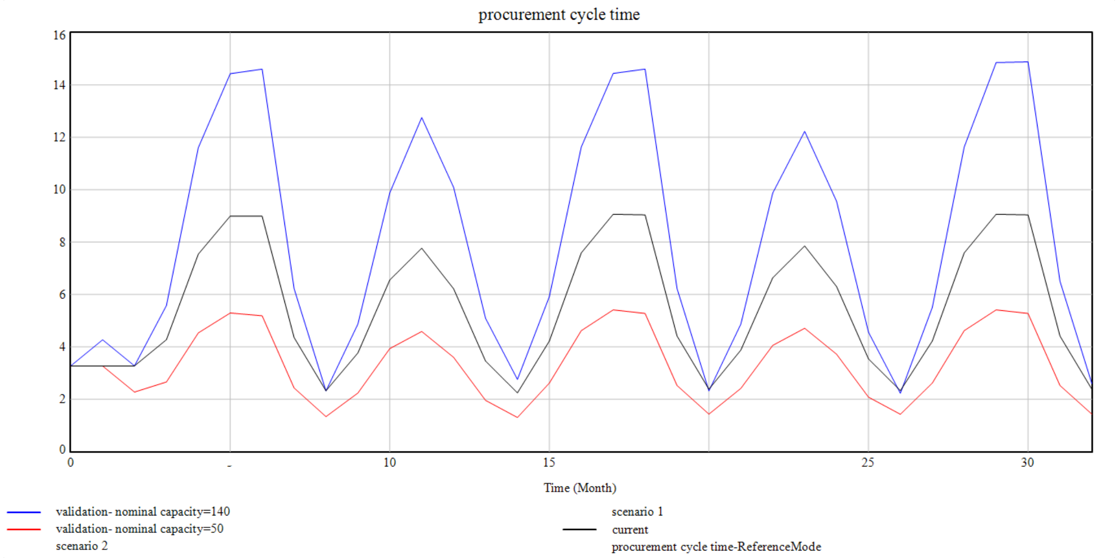

Figure 29. The second validation test (procurement cycle time with nominal capacity 20 and 140)

If the total capacity of the supplier is reduced, the amount of capacity allocated to the firm will be reduced, so the order supply time will also increase. As a result, the procurement cycle time also increases. This behaviour can also be seen in Figure 11.

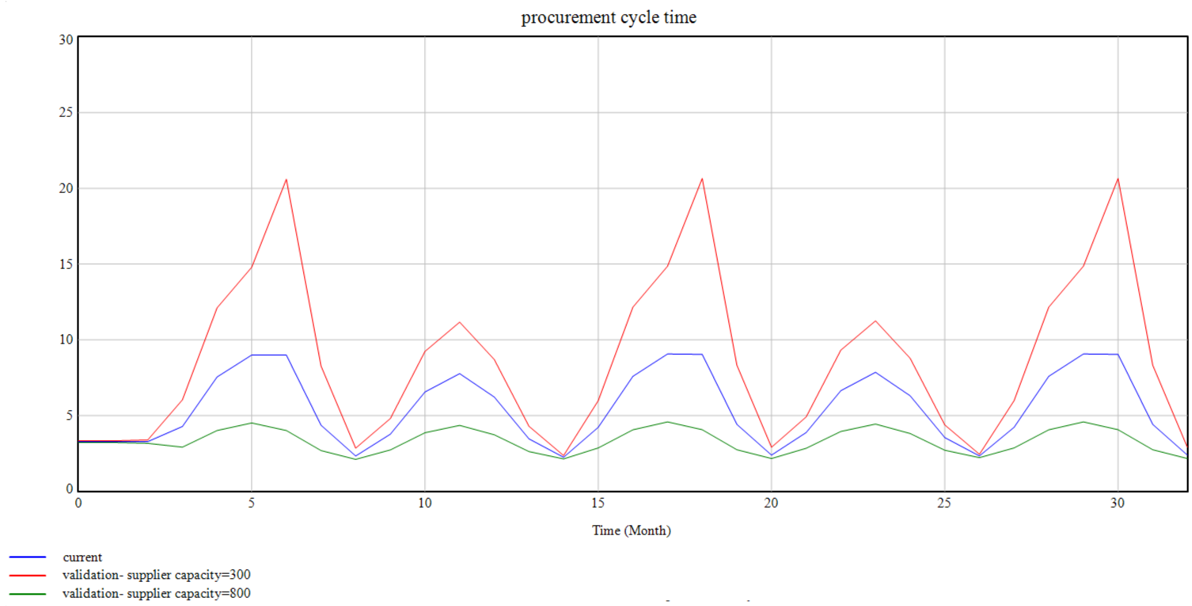

Figure 30. The third validation test (procurement cycle time with supplier capacity of 300 and 800)

As can be seen from Figures 10 and 11, either the nominal production capacity and the supplier's capacity change, the procurement cycle time will be affected so that by increasing the supplier's capacity and decreasing the nominal production capacity, the procurement cycle time can be reduced.

6. Discussion

As far as we know, there are not many papers addressing the procurement cycle time reduction issue. Laradi et al. developed a simulation model to measure the procurement cycle time under outsourcing and insourcing policy (Laradi, et al., 2015). They considered the effect of technical expertise and project financing as two major factors. Nicoletti studied the procurement process performance under the lean thinking methodology (Nicoletti, 2018). He showed applying this approach could result in the reduction of waste in procurement and also a decrease in overall procurement cycle time. In this research, an attempt has been made to investigate the effect of various factors on the increase in procurement cycle time using a model and to reduce this time as much as possible by applying policies.

For this purpose, one of the policies that can be considered is renting the supplier's capacity by the firm. The seasonal demand affects the supplier's capacity to meet the firm's demand, causing fluctuations in the procurement lead time. Renting a certain percentage of the supplier's capacity can reduce these fluctuations, reducing the procurement cycle time. Another way that can be considered to reduce the procurement cycle time is to reduce the time of the internal procurement process. Since the major part of the internal procurement process is the time of major transactions, the firm can reduce this time by adopting processes such as process automation. Since both these policies are costly for the firm, it is worth studying the effects; therefore, one can cost-benefit and prioritize these initiatives. As shown in Figure 12, applying this policy reduces the procurement cycle time by 16% on average in different periods. This ultimately leads to a 5% reduction in the average procurement cycle time in different intervals. In addition, another solution that can be presented is the combination of the two policies. In this sense, if the firm has enough budget and time to implement both policies, it can combine the two policies, which ultimately reduces the procurement cycle time by 22% on average. Table 1 shows a summary of the impact of these policies.

Table 13. The impact of policies

Row	Policy	Impact
1	Renting Supplier production capacity	16% reduction in procurement cycle time
2	Reducing the average time of major transactions	5% reduction in procurement cycle time
3	Combining the above two policies	22% reduction in procurement cycle time

As seen in Figure 12, if it is possible to apply both policies in combination, the greatest improvement is achieved. Otherwise, according to Figure 11 and simulation results, it is better to apply the first policy first.

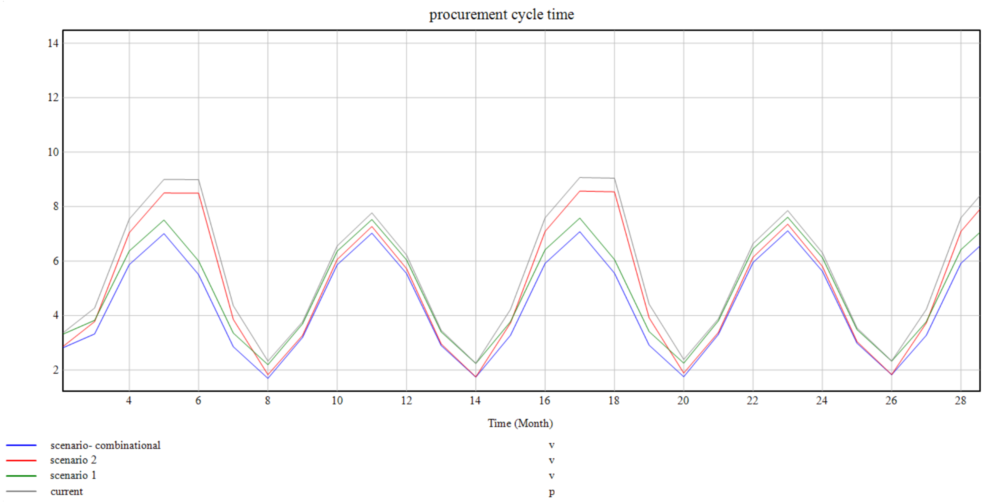

Figure 31. Comparison of procurement cycle time in different policies

7. Conclusion

This research attempted to examine one of the most important criteria of procurement process agility, i.e., procurement cycle time with a systems approach. Based on a case study, a system dynamics model describing affecting factors on procurement cycle time was presented and validated according to the available data from the process. Then several policies were proposed to improve this agility index. Finally, the presented policies were analysed numerically, and according to the results of this research, the effect of reducing the order supply time on the procurement cycle time is greater than reducing the time of the internal procurement process; This issue can help firms as a management tip. According to the results obtained from the simulation of the presented model, the combination of the presented policies leads to a 22% reduction in the average procurement cycle time. For future research, in addition to the procurement cycle time, other topics affecting the agility of the procurement process, such as flexibility, can also be considered. It is also possible to examine other market dynamics that affect the demand factor, such as global disruptions in the supply chain, political and social conditions, the spread of infectious diseases such as Corona, and other such factors.

Disclosure statement

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

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Improving the Allocation of Resources to Different Strategies of Medical Equipment Maintenance and Repair with System Dynamics Approach Case study: Razavi Hospital of Mashhad

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ABSTRACT

Appropriate maintenance strategies reduce the overall operating cost of medical equipment and its depreciation, leading to increased equipment availability. This study is looking for an optimal strategy to increase access to medical equipment and reduce maintenance costs. It generally aims to increase the net value of the equipment maintenance system. The present study has designed a simulation model of dynamic systems in order to investigate the contribution of preventive and corrective maintenance measures and strategies to improve the overall performance of medical equipment. In this regard, first, the key variables in the maintenance and repair system of medical equipment have been identified, and their relationships have been compiled in the form of causal loops; then, the primary model has been completed in the form of stock and flow charts which have been simulated in Vansim software. The results show that increasing preventive maintenance by reducing the need for corrective measures leads to increased access to equipment and reduced maintenance costs. The ratio of change of resources and the amount of its allocation to each of the corrective and preventive maintenance measures have been obtained through simulation and according to the amount of primary and secondary variables in the case of the study (Razavi Hospital). The simulated model can be implemented for other hospitals considering their internal conditions.

Keywords

Maintenance strategies, Medical equipment, System dynamics, Optimization, Simulation.

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1. Introduction

Modern medical devices and equipment have become complex and sophisticated and are expected to operate under stringent environments. Hospitals must ensure that their critical medical devices are safe, accurate, reliable and operating at the required level of performance. The most significant problem for many developing countries is not the lack of equipment but rather the fact that 50% and sometimes up to 75% of the supplied equipment is not operative (Gómez-Chaparro et al. 2020). The maintenance of medical equipment is as essential as its design and development. The cost of maintaining a medical device during its lifetime is usually higher than purchasing it (Darzi et al., 2019). Medical equipment technologies require planned and unplanned maintenance, and in recent decades, their maintenance cost has increased dramatically due to the increasing costs of medical equipment (Ahmed, 2016). Due to the high cost of purchasing medical equipment, it is vital to maintain this equipment in order to control hospital costs efficiently. On the other hand, one of the most critical problems faced by medical staff in hospitals is the unavailability of medical equipment when needed due to the malfunctioning of the medical equipment repair and maintenance system. An appropriate maintenance system is required for almost all equipment in order to guarantee performance and accessibility (Almakrami, 2021).

Incidentally, the medical maintenance of large-investment resources, which was once thought to be a necessary evil, is currently essential in creating additional value. The first challenge for medical departments is to define which maintenance strategy should be deployed for each piece of equipment (Mahfoud et al. 2017). Now, strategies mainly implemented for most hospital equipment include corrective and periodic preventive maintenance.

Corrective Maintenance (CM) is carried out after a fault has been recognized; it is intended to put the failed item back into a state where it can perform its required function. PM is carried out at predetermined intervals or according to prescribed criteria and is intended to reduce the probability of failure or the degradation of items (European Committee for Standardization, 2010). The selection of a maintenance strategy depends on a number of factors, including the cost of downtime, redundancy and the item's reliability characteristics. Consequently, this issue varies among organisations and assets despite the importance of establishing a balance between PM and CM in minimizing costs (Stenström, 2015).

The present study, by reviewing the available resources regarding the selection of medical equipment maintenance strategies, seeks to provide a comprehensive approach by considering the interaction between effective factors affecting the selection of maintenance strategies. It tries to determine the optimal number of resources allocated to each corrective and preventive maintenance action by establishing a reasonable balance between corrective and preventive maintenance costs. Research regarding the determination of maintenance strategies of medical equipment as well as the application of the system dynamics in the field of maintenance and repair are as follows:

Medical technology management plays a crucial role in health care. Effective medical device management is required to ensure high-quality patient care. Efficient and accurate equipment provides a high degree of patient safety. Accomplished medical device management will significantly assist in reducing adverse incidents and medical device-related accidents. For medical technology management, hospitals must have activities for maintaining, inspecting, and examining all medical equipment in the inventory (Sezdi, 2016). Preventive maintenance is a core function of clinical engineering, and it is essential to guarantee the correct functioning of the equipment. As the variety of medical equipment increases, the size of maintenance activities increases, and the need for better management and control becomes essential (Dejaco et al., 2019). According to Jamshidi et al. (2014) preventive maintenance will reduce major repairs and prevent inappropriate performance of medical equipment. Preventative maintenance exists in many industries and was previously used in health centers only for heating and air conditioning systems, but recently it has been used for medical equipment too. A preventive maintenance strategy is the essential maintenance activity of medical devices. Other factors, such as the "medical equipment control program" and "appropriate medical equipment selection", will help implement the optimal maintenance program. Generally, the preventive maintenance process prevents device wear-out or improper functioning of medical devices and prolongs the life of medical equipment; thus, medical devices are kept in a desirable condition and do not quickly deteriorate (Zamzam et al., 2021). Bahreini et al. (2018), emphasizing the importance of medical equipment repair and maintenance strategies and the impact of medical equipment on the mortality rate of patients, have presented a model for prioritizing the repair and maintenance of medical equipment in Jordanian hospitals. The results of their study show that the application of this model has a significant impact on minimizing equipment malfunctioning, increasing its reliability, cost savings and improving the safety of the equipment. Mekki et al. (2012) developed a model for enhancing medical equipment repair and maintenance programs in developing countries using a system dynamics approach. They have proposed their model in 3 hospitals in Sudan and 12 hospitals in Egypt. Their results revealed that the failure rate, the rate of disabled machines and maintenance costs are the most critical factors affecting a system of maintenance and repair of medical equipment. In 2015, Jamshidi et al. proposed a risk-based priority framework for choosing the best maintenance strategy. This framework consists of three main stages: the first phase is the fuzzy analysis of failure factors and their effects (FFMEA). In the second stage, all aspects of risk are considered in prioritizing medical equipment. Finally, in the third stage, each piece of equipment's most appropriate maintenance strategy is proposed according to its rating. The results of their study show that managers can use this framework to classify medical equipment according to the obtained ratings and required maintenance activities and increase access to high-risk equipment. In 2015, Abdo et al. used a system dynamics approach to assess medical equipment repair and maintenance systems in developing countries. In their study, they designed a model for determining the contribution of corrective and preventive maintenance strategies in order to improve the overall performance of medical devices. Indeed, their study has provided a desirable maintenance strategy to increase the operational accessibility of medical devices and reduce their deterioration.

Compared to the previous studies, the innovation of this paper is that the model presented in this research is more complete than the previous research by considering different subsystems, including cost, availability and number of defects. A more comprehensive model than past studies has been designed to show a more accurate picture of the dynamic behavior of the medical maintenance and repair system using the concept of a system dynamics. This paper aims to create a dynamic system model to increase the effectiveness of medical equipment over its lifespan by monitoring the performance of medical equipment and developing appropriate maintenance strategies. This paper presents a dynamic hypothesis, and then the model's critical variables are identified. To illustrate the relationship between variables, the Causal loop diagrams have been developed. In the next step, the stock and flow diagram of the medical equipment maintenance system is mapped, and finally, the model is simulated in the form of three different policies.

2. Methodology

In this study, a questionnaire consisting of 18 questions was used to collect data on the variables identified in the model. It should be noted that this paper focuses on maintenance strategies of the equipment in the ultrasound section of Razavi Hospital. The relevant questionnaires were completed through face-to-face communication. Aggregated data is only used to determine the initial position of the system, to set the range of variables and to present real policies. Also, the hospital records of previous years have been used to provide reference modes. Vensim software was used in this research, a visual modeling tool that allows the conceptualization, documentation, simulation, analysis and optimization of dynamic system models. Generally, Vensim is a simple, flexible way to simulate dynamic systems models using a Causal loop and stock and flow diagrams (Vensim, 2007). There have been several tests to validate the model; in this study, the extreme conditions test is performed to check whether or not the equations make sense when subjected to extreme conditions (Ahmad et al. 2015). Extreme condition analysis analyzes if the parameters in the model behave appropriately under extreme conditions. To assess this response, surfaces were compiled for each endogenous variable (Nazareth et al. 2015).

3. System dynamics model

This section reviews a systemic view of maintenance by establishing a system dynamics model. This model considers the relationships between corrective and preventive maintenance actions, equipment breakdowns, equipment availability and process quality. The model uses the causal loop diagram and flow diagram to depict processes, concepts and interdependencies used in system dynamics.

3.1. Dynamic hypothesis

The allocation of available resources for corrective and preventive maintenance actions through dedicating a larger budget and human resources will reduce the average time required for each equipment repair. As a result, the repair rate increases and their defect rates decrease. By lowering the defect, the average time between the two breakdowns has increased; in fact, the number of hours that the device is out of service decreases, increasing the accessibility to devices. Also, reducing equipment deficiencies by reducing the number of hours that devices operate despite the defects will improve the functionality of the equipment and thus increase access to them. On the other hand, with the increase in preventive maintenance actions, the number of devices that operate without defects will increase the equipment's functionality and, consequently, its access. With an increase in the availability of devices, if there is a demand for them, the number of operating hours of the devices increases, which will result in equipment wear and tear and, consequently, an increase in the rate of the defect and the number of breakdowns. Ultimately, it reduces access to the device. In general, the balanced allocation of maintenance resources to preventive and corrective maintenance actions will increase access to equipment and reduce maintenance costs, including maintenance and repair costs, and finally, the net worth of the maintenance strategy increases.

3.2 Causal loop diagram

Following the dynamic hypothesis, the causal loop diagram is created. In Figure 1, the causal loop diagram of the medical equipment maintenance system is presented. This diagram is used to display the feedback structure of the system, and it contains two or more causal relationships that link various variables to the model. Feedback is a key concept in the dynamic system showing the interactions between variables. In general, there are two feedback loops: positive or self-reinforcing loops and negative or self-equilibrium loops. Positive loops increase the growth effect exponentially, while negative loops, according to the equilibrium approach, reduce the gap between the existing system and the equilibrium state. The causal diagram shown in Figure 1 can be divided into two subsystems, a maintenance subsystem and a preventive or periodic maintenance subsystem. These two subsystems are connected by the variables of availability and maintenance costs. Failure and function have a negative and positive effect on availability; however, the impact of device availability on the two variables of failure and function is positive. Therefore, there are two loops: the loop between the function and availability, which is positive and the loop between the failure and availability, which is negative.

Since allocating more resources and personnel for maintenance will lead to increased costs and thus reduce the effectiveness of maintenance strategies, the cost variable is also presented in the causal diagram. In this paper, the increase in resources and personnel allocated for repairs leads to a doubling of the cost of corrective maintenance; there is a positive and exponential relationship between preventative maintenance actions and related costs.

The model output and basis for subsequent decision-making are the net maintenance value. The net maintenance value is affected by two variables: the availability of the device and the cost of maintenance which can be used to analyze maintenance actions and strategies.

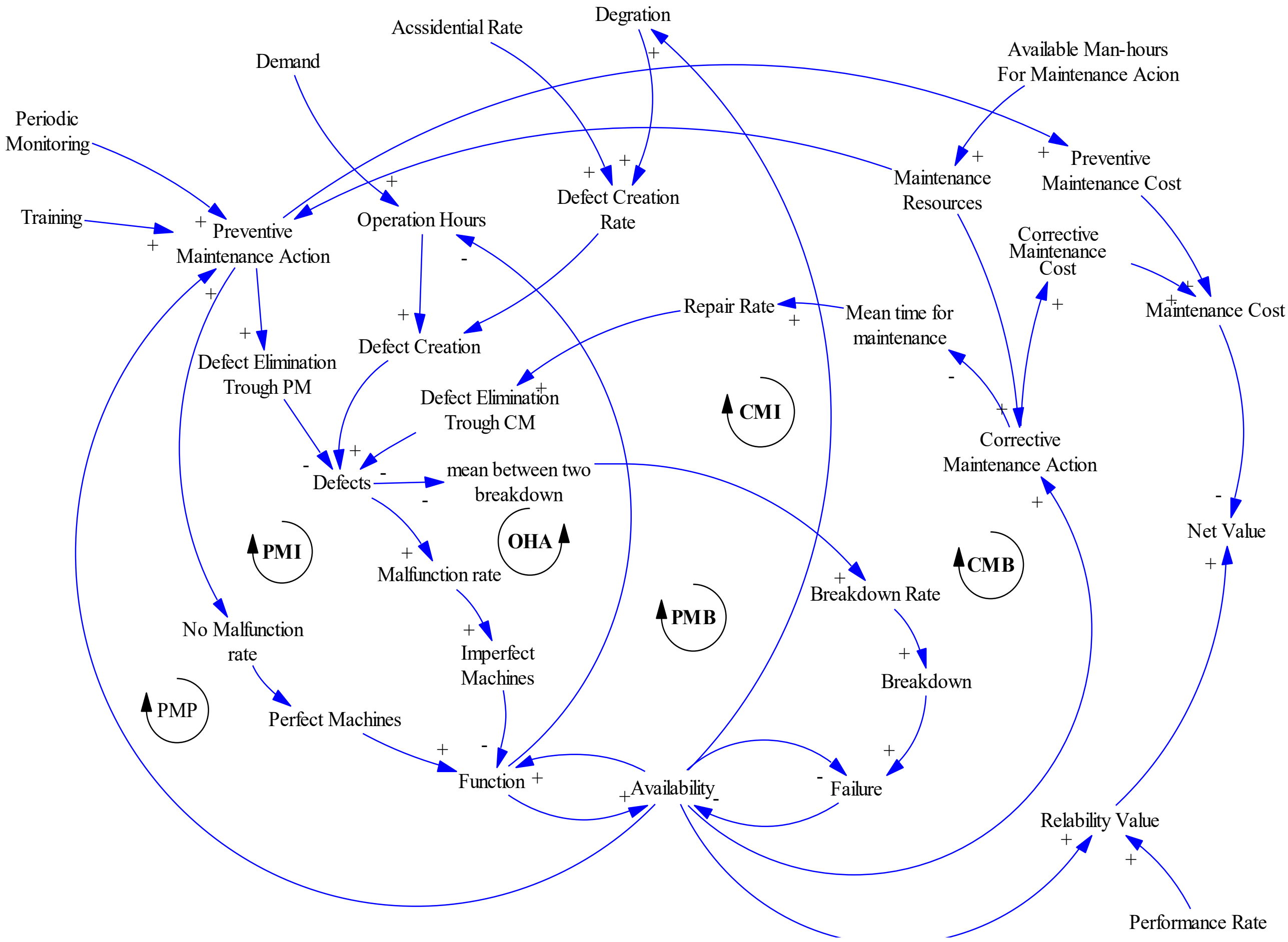

Figure 32. The causal loop diagram of the medical equipment maintenance system

3.3. Stock and flow diagram

In Table 1, the characteristics of the identified variables are presented. According to engineers and maintenance managers of the hospital, the set of variables presented is the starting point for modeling the system.

One of the most critical limitations of the causal loop diagrams is their inability to display the stock and flow structure of the system. Stocks and flows, along with feedback, are two key concepts in dynamic systems. Generally, stocks occur in a system due to the difference between the rates of input and output flows during a process in the system. Stocks lead to the creation of memory in the system as the basis for actions and decisions in the system. Stocks also cause delays and imbalances in the system.

Based on the research question and the causal loop diagram, since the purpose of the research is to improve the outcomes of the medical equipment maintenance system, the variables of the number of defects along with the total cost of maintenance and availability are considered as the stock variables, and the net value variable is the output variable as the ultimate goal of the research. For better understanding, each of the subsystems of the stock and flow diagram is examined separately.

Table 14. The key variables' definition and formulation

Variable	Unit of measurement	Kind of variable	Definition	Formulation
Availability	Hours	Stock	The number of hours the device is available to be used and perform task operations	$\int (function - failure)dt$
Function	Hours per month	Flow	The number of hours that the device is in the functional state each month (including correct operation and acceptable operation)	$perfect + 0.5 * imperfect$
Corrective Maintenance Cost	Currency in month	Flow	The monthly costs for corrective maintenance actions are shown	$\mathrm{MIN(CM\ resource\ rate * maintenance\ resource, 4 * break\ down + imperfect)}$
Defect	Number	Stock	The total number of defects that result in poor performance of the device or its disability.	$\int defect\ creation - (defect\ elimination\ by\ PM + defect\ elimination\ by\ CM)dt$
Preventive maintenance cost	Currency in month	Flow	The monthly costs for preventive maintenance actions are shown	$maintenance\ resource * PM\ resource\ rate$
Total maintenance cost	Currency	Stock	The total amount of money allocated to corrective and preventive maintenance actions.	$\int (CM\ cost + PM\ cost)dt$
Device failure	Hours per month	Flow	The number of hours the device is out of service in the month.	$break\ down\ rate * Defects$
Defect creation	Number per month	Flow	The number of defects created in the month	$defect\ rate * operational\ hours$
Elimination of defects through CM actions	Number per month	Flow	The number of defects that are resolved in the month through corrective maintenance actions	$PM\ action * PM\ rate$
Elimination of defects through PM actions	Number per month	Flow	The number of defects that are resolved in the month through preventive maintenance actions	$DELAY1(CM\ action, 25)$

As shown in Figure 2, failure and function negatively and positively affect availability in the availability subsystem. In contrast, the effect of device availability on these two variables (failure and function) is positive. The degree of disruption and defect in the device, as well as the perfect device, has a direct impact on availability.

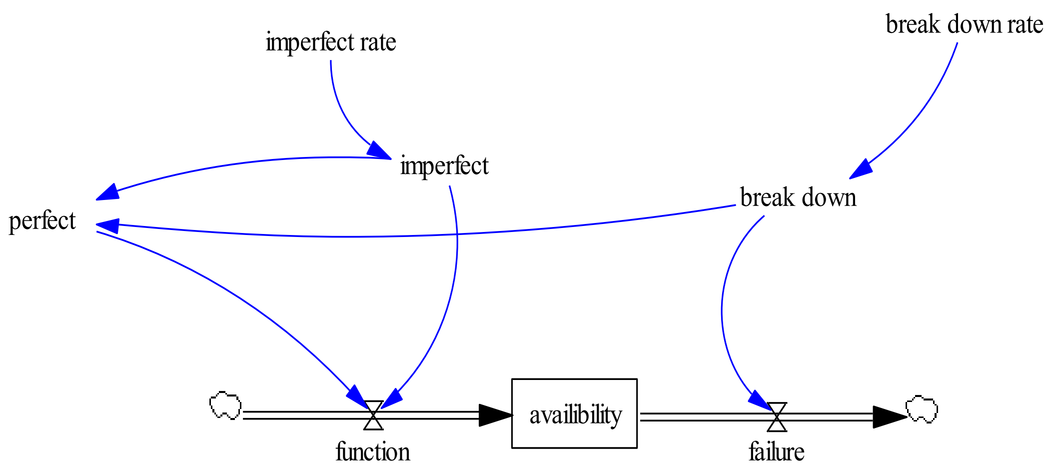

Figure 33. The stock and flow diagram of the availability variable

Figure 3 below shows the system failure. This subsystem examines the relationship between preventive and corrective maintenance strategies and the degree of defect in the device. Increasing available resources for maintenance will lead to an increase in corrective maintenance actions through more resource and manpower allocation. Thus the average repair time is reduced, which means that the repair rate has increased and the amount of defect (flow and stock) decreases. As a result of reducing the defect, the number of hours the device is out of service is reduced and eventually, the device's failure rate is reduced too. On the other hand, increased maintenance resources will increase preventive maintenance actions, including replacement policies and technical actions. Therefore, the number of hours the device is defective decreases, and the average time between failures increases, which results in a decrease in the failure rate and the number of hours the device is out of service, and ultimately the failure rate of the device decreases.

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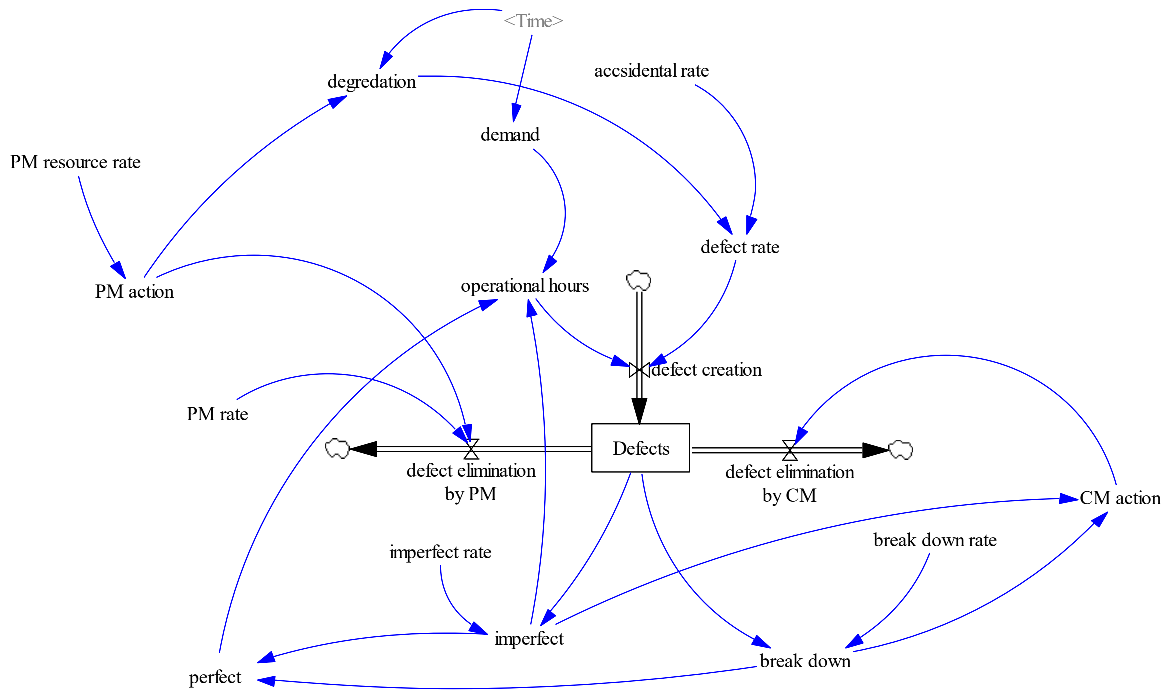

Figure 34. The stock and flow diagram of the defect's variable

As shown in Figure 4, the maintenance subsystem reflects the level of the actions of each corrective and preventive maintenance strategy and the total maintenance cost. The amount of corrective maintenance strategy actions depends on the percentage of the allocated resources and the degree of breakdown and disruption of the device; on the other hand, the amount of preventive maintenance strategy actions depends on the allocated resources.

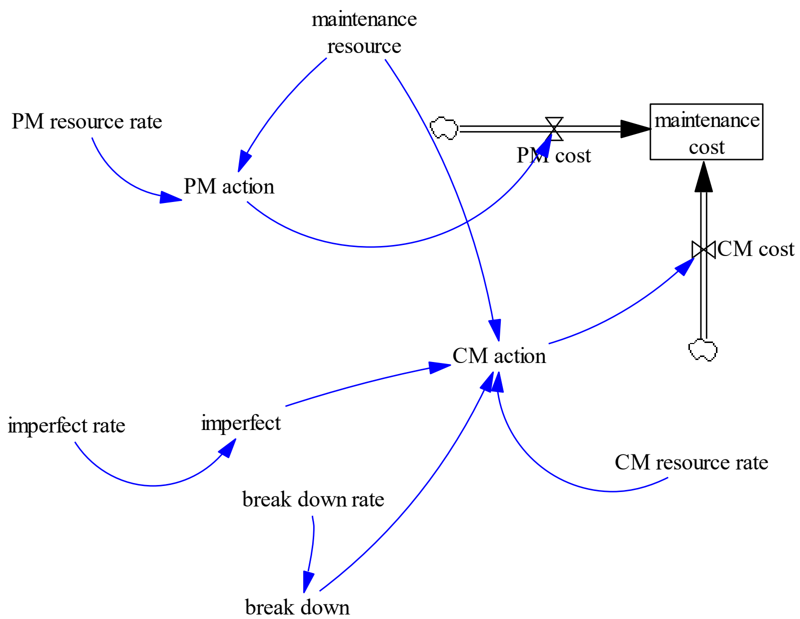

Figure 35. The stock and flow diagram of the maintenance cost variable

An integrated stock and flow diagram is presented in Figure 5, and it is the result of the integration of three subsystems of defects, availability of the device and maintenance costs.

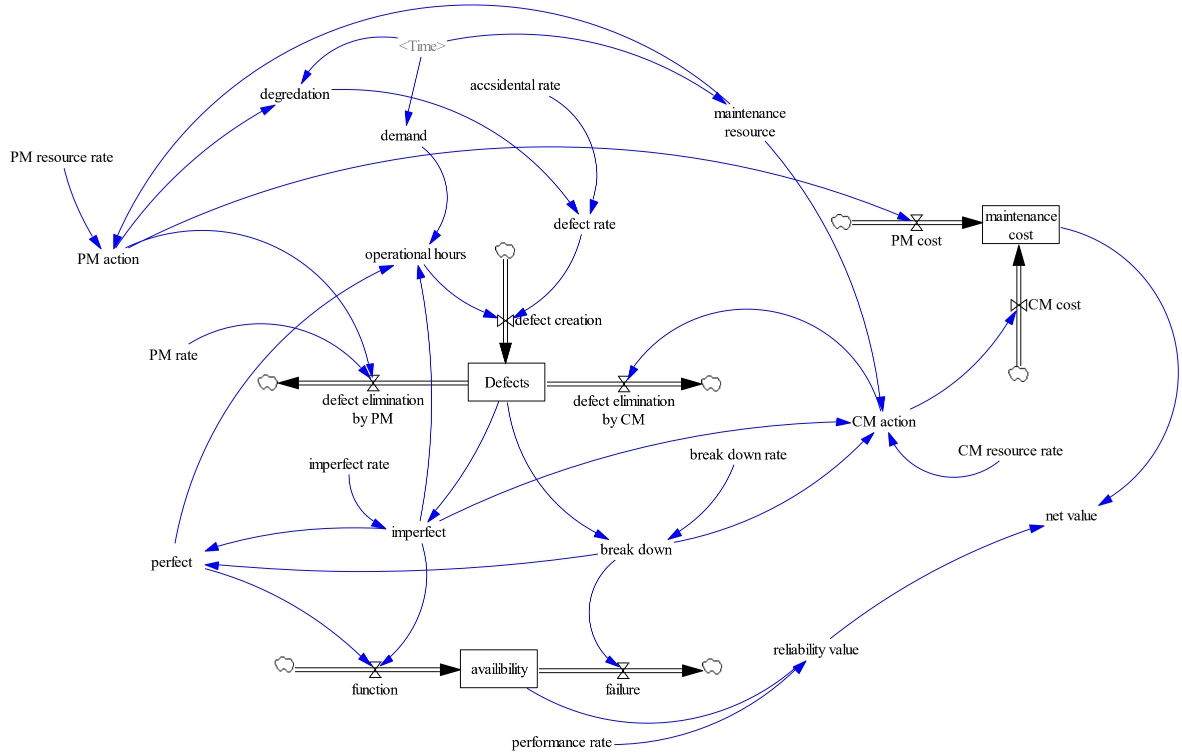

Figure 36. The stock and flow diagram of the system of medical equipment maintenance

3.4. The model validity

System dynamics models' validity is divided into structural and behavioral validity. Structural validity means creating relationships in the model that represent the relationships of the real world (taking into account the purpose of the study) expressively and adequately (Oliva, 2003). Behavioral validity means that the model's behaviour sufficiently represents the phenomenon's behaviour in the real world. The structural validity of the model has priority over its behavioral validity, and only when the structure of the model is valid can the validity of its behavior be investigated (Khan, 2009). Therefore, in the present study, an extreme conditions test has been used to assess the validity of the model. Considering the main parameter in the minimum and maximum mode and the output test of the model is the method of this type of validation to check its sensitivity to these changes. Although the graphs from extreme points may never be observed in real terms, the logical behavior of the model is expected. For this purpose, on one side of the spectrum, the percentage assigned to the corrective maintenance strategy is zero, and the preventive maintenance strategy is 100. On the other side, the percentage considered for the corrective maintenance strategy is 100, and for the preventive maintenance, strategy is zero. In reality, in matters relating to the repair and maintenance of medical equipment, the above conditions will not occur due to repairs needed in emergency conditions, and this is only for validating the behavior of the endogenous variables.

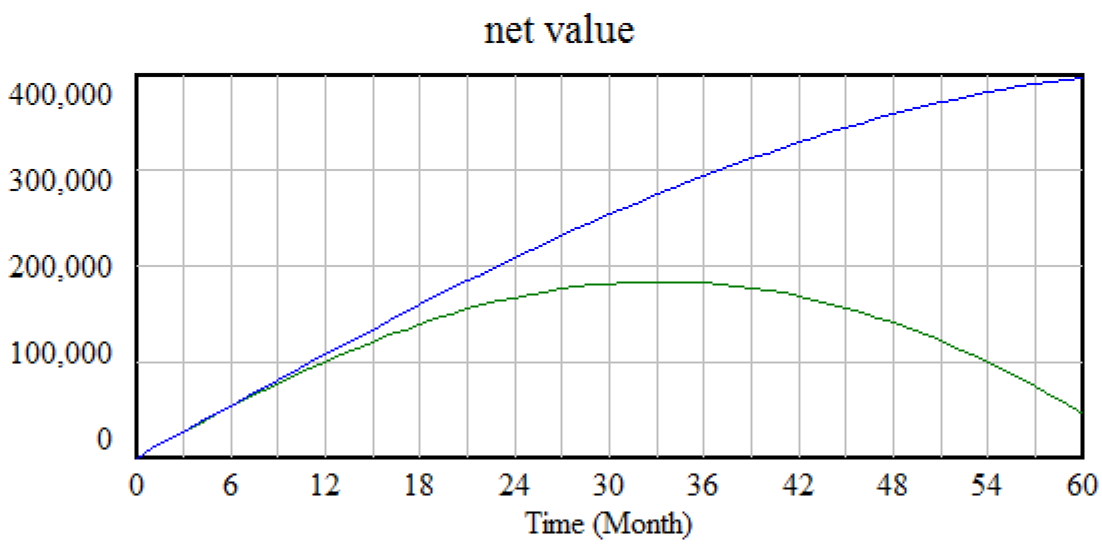

Figure 37. The extreme conditions test of the net value variable

As shown in the Figure 6, by allocating the total budget to preventive maintenance, the net value of the system will be an uptrend. On the other hand, by allocating the total budget to corrective maintenance, the net value of the system after some time will be downtrend towards zero. Observing these logical behaviors of the system at extreme points will verify the model's validity.

4. Results and discussion

This section examines various policies regarding allocating maintenance resources to preventive and corrective maintenance strategies. The first policy is to review the process of maintenance strategies in the current situation, meaning that no changes to the current corrective and preventive maintenance policies are applied. In fact, in the present condition of the hospital, the resources available for maintenance are allocated equally to the corrective maintenance and preventive maintenance strategies. In the second policy, the ratio of resources and personnel allocated to corrective maintenance increased from 50% to 70%, and the resources and personnel allocated to preventive maintenance decreased from 50% to 30%.In the third policy, the percentage of resources allocated to preventive maintenance increased to 70%, and it was reduced to 30% for the corrective maintenance strategy. The flow and a stock diagram for the three variables of availability, net value and maintenance costs for the above policies are presented in Figures 7, 8 and 9, respectively.

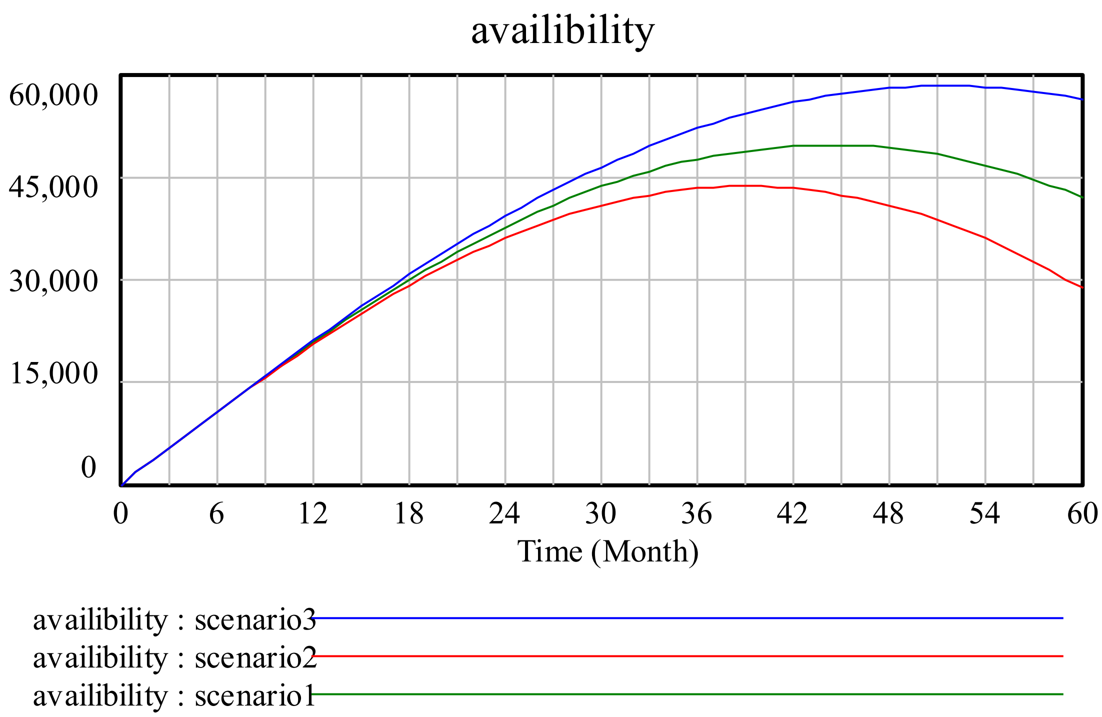

Figure 38. The stock and flow diagram of the availability of equipment for various policies

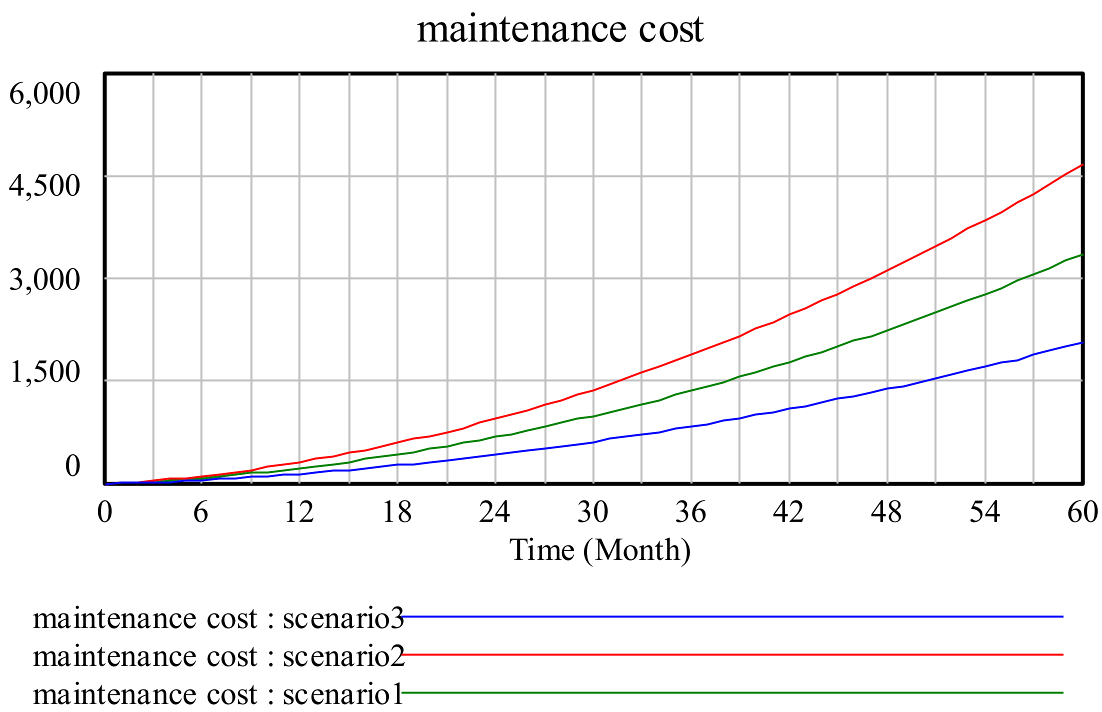

Figure 39. The stock and flow diagram of maintenance cost for various policies

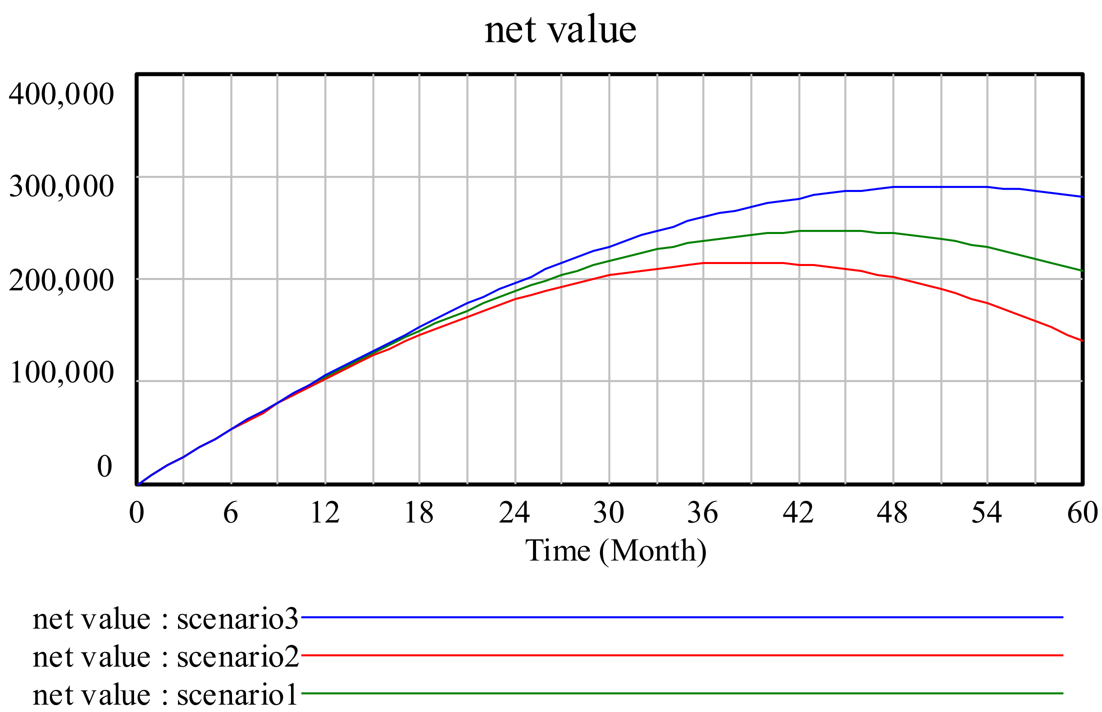

Figure 40. The stock and flow diagram of net value for various policies

As shown in the above diagrams, the changes made in the above policies lead to changes in the level of availability, net value and maintenance costs of maintenance strategies.

The area under the curve for each policy identifies the best maintenance strategy to be chosen by decision-makers. In fact, the policy that has the highest area under the curve, according to formula (1) is the best policy. In fact, the policy that has the highest area under the curve is the best policy.

$$Area = \int Net\ valu(t)dt = \sum Net\ value(t)dt\ \times \Delta t \tag{1}$$

The area under the curve for availability and net value diagrams is the highest for policy 3 and is the lowest for policy 2, and the area under the curve for policy 1 is between these two policies. As seen in the diagrams above, there are no significant differences in the policies in the early months. Still, over time, policy 3, which allocates a greater share of resources to the preventive maintenance strategy, has the highest area for availability and net value and the lowest area for maintenance costs. Therefore, based on the values of net worth, availability and maintenance cost, policies 3, 1 and 2, respectively, are proposed to develop maintenance strategies for Razavi Hospital equipment.

5. Conclusion

This paper uses a dynamic system approach for modeling hospital maintenance programs (ultrasound section of Razavi Hospital) and resource sharing between various equipment maintenance strategies. According to this approach, a causal loop diagram has been used to provide causal relationships among identified key variables. Also, the stock and flow structure was used to simulate the proposed system. The model presented in this study is more complete about the cost and availability of defects subsystems than previous research. The advantage of this article over previous papers is that the net worth variable, which is the result of two cost and availability variables, is added to the model and allows a more accurate decision-making policy. In previous articles, maintenance or machine disruption variables were considered the final variables of the models. Due to the interaction between the variables and the effects of factors such as functionality, reliability and availability, those models lacked comprehensiveness. At the same time, this paper attempts to present a comprehensive model that illustrates a more accurate picture of the dynamic behavior of the medical maintenance system using the concept of a dynamic system.

In this paper, various maintenance strategies were considered regarding the proposed model and then, based on the net value of each strategy, the contribution of each strategy was determined from resources. In fact, the strategy that has the highest net worth is considered the best strategy. Based on the simulation results and the examination of different policies, we conclude that investing in different maintenance strategies in the early years does not make any significant changes in the outputs of the model; in other words, different strategies do not differ significantly. But investing more in the preventive maintenance strategy and allocating more resources to this strategy will lead, in the long run, to higher levels of equipment availability and net worth in comparison with the other two strategies proposed in this paper.

Considering the huge investment in the medical equipment sector of the country's hospitals, the importance of having a precise system for repairs and maintenance is clear. Detailed planning can increase the system's useful life and reduce costs. Due to the lack of accuracy and attention to proper maintenance, and lack of timely system repairs, the devices are depreciated and retired before they reach the end of their useful life, and the high costs incurred for their early replacement. Using the right maintenance strategy and allocating the required budget can lead to better functioning of the devices and significant cost savings. This research showed that the simulation approach based on system dynamics in the health field could analyze the future and examine the facts and the impact of policies more precisely. In this study, it has been shown that investing in different maintenance strategies in the early years does not create noticeable changes in the model outputs, but investing more in preventive maintenance strategies. In the long term, it will lead to positive and significant changes in the outputs of the model compared to the other two strategies. Increasing the awareness of medical equipment specialists, empowering them and supporting senior managers from the achievements of this research can have increasing effects in reducing repair costs and maintaining and extending the life of medical equipment.

Adding other subsystems can improve and adapt the current model to every hospital's internal conditions. Hospital internal policies, the effectiveness of maintenance personnel, training and development of human resources, and how to deal with competitors (in private hospitals) are also the components that make the model presented in this research more complete.

Disclosure statement

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

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Designing a Sustainable Entrepreneurship Development Model for Iran's Agriculture: Application of Interpretive-Structural Model (ISM)

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ABSTRACT

Due to the lack of attractiveness of agricultural entrepreneurship, a significant part of Iran's agricultural capacities has not been properly utilized. This study focused on identifying and analysing the obstacles to developing sustainable agricultural entrepreneurship in Iran. To this end, identifying barriers was conducted using the Fuzzy Delphi method and data were gathered through interviews and questionnaires. In the following, the obstacles were analysed using the ISM approach and with the participation of a group of 8 experts. An interrelationship diagram of the obstacles was designed at five levels. At the fifth level, the fundamental obstacles included a lack of sustainable agricultural entrepreneurship development strategies in the country's macro development plans, the dependence of financial resources of the agricultural sector on the government banking system and government subsidies, lack of sustainable agricultural entrepreneurship consulting services, insufficient attention to research and low participation on the part of universities and research institutes. This indicates the immense impact of such barriers on the trajectory toward the realization of sustainable agricultural entrepreneurship. At the fourth level, lack of binding laws to assure compliance with environmental standards lack of formal training; At the third level: Lack of incentive policies to increase private sector involvement in providing capital for owners of entrepreneurship ideas, a lack of recognition of opportunities in line with the region's climate, lack of distribution channels in the target markets of sustainable agricultural entrepreneurship opportunities, and lack of social development toward creating values and establishing innovative and creative sustainable agricultural businesses; At the second level, lack of knowledge on agricultural entrepreneurship opportunities in optimizing cultivation and water consumption patterns, lack of product pricing systems, and inappropriate marketing; and at the first level, lack of investment in knowledge-based and technological opportunities have been identified as the most susceptible obstacles in realizing sustainable agricultural entrepreneurship.

Keywords

Sustainable Development, Sustainable Entrepreneurship, Agricultural Entrepreneurship Obstacles, Interpretive Structural Modelling (ISM).

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1. Introduction

Sustainable development conceptually stems from the promotion of sustainable use of natural resources. Sustainability concerns have gained increasing significance among organizations and their stakeholders worldwide. In this regard, adaptation to the environment has become an instrument for the transition to sustainable development. Sustainable development does not aim to preserve the status quo but considers the transition of resources to future generations. On the other hand, in recent years, there has been a growing interest in exploiting entrepreneurial competencies to solve problems and foster improvements in the components of sustainable development, which include social, environmental and economic dimensions (Davies and Chambers, 2018). Sustainable entrepreneurs focus on identifying new business opportunities that lead to developing products or processes that are more sustainable than what is currently available (Schaltegger et al., 2016). Lüdeke-Freund and Dembek (2017) define this entrepreneurship as a voluntary commitment to creating social and environmental value beyond ordinary business occupations while creating economic value. Sustainable entrepreneurs observe environmental considerations through every stage of creating and developing their business and play a greater role in improving resource utilisation efficiency, mitigating environmental risks and hazards, reducing waste and ensuring cultural and social quality. Sustainable entrepreneurship is closely connected with social responsibility and environmental development, for it reflects the involvement of entrepreneurs in various social and environmental dimensions (Spence et al., 2011).

Agriculture has become the basis of development in many countries, and this sector is also critical in Iran. FAO reports rank Iran among the world's top 7 countries in agricultural production (FAO, 2017). Enjoying different weather conditions and diversity in terms of topography, Iran has various agricultural products. This sector can play a major role in economic prosperity. However, investigations reveal that despite all the efforts made in the agriculture sector in recent years, this sector is facing bottlenecks regarding development due to structural problems. Despite all the potential and actual talents and abilities, Iran's agriculture sector is allocated only a 5-10% share of the country's gross domestic product. According to the Agricultural Research Education and Extention Organization (AREEO) announcement, the number of farmers drops by an average of 50 thousand people yearly due to the lack of facilities and attractions in the agriculture sector (OECD-FAO, 2019). Statistics show that a significant part of Iran's agricultural capacities has not undergone proper exploitation. However, FAO has announced that Iran's natural resources have the potential to supply the countries in the Persian Gulf region in addition to its own food supply. Given that the paradigm of entrepreneurship is concentrated on creating new value by taking advantage of opportunities, Iran's agricultural sector is facing many obstacles and complications in developing sustainable entrepreneurship. This study intends to identify obstacles to sustainable entrepreneurship development in Iran’s agriculture sector by reviewing the studies and using experts' opinions. The design of the sustainable agricultural entrepreneurship development model based on analysing the critical sustainability obstacles is research innovation.

2. Literature review

According to the current research problem, after reviewing the relevant literature, the background of the research conducted on sustainable agricultural development, sustainable entrepreneurship and agriculture entrepreneurship was analysed, and an attempt was made to take into consideration the obstacles to the development of sustainable agricultural entrepreneurship and to summarize these obstacles by using the literature review.

The concepts and a number of studies are presented as follows. Sustainable agriculture is considered an approach to ensure economic, social and ecological sustainability. Applying entrepreneurial ability to address sustainable development is called sustainable entrepreneurship in sustainable entrepreneurship literature (Schaltgger and Wagner, 2011). Sustainable entrepreneurs focus on identifying new business opportunities that lead to developing products or processes that are more sustainable than what is currently available (Schaltegger et al., 2016). The literature was analysed regarding agricultural sustainability development, sustainable entrepreneurship and agricultural entrepreneurship. In general, studies conducted in the field of agricultural development are of great interest, and most emphasize the productivity of factors of production.

Hosseinzadeh et al. (2022) identified the dynamic complexities and development points of the entrepreneurial ecosystem (EE) in Iran's agricultural sector to improve the productivity of production factors, including arable land, water resources and human resources capital. Keyhanpour et al. (2021) modeled the water-food-energy nexus, showed that food resources security in Iran would be in jeopardy in the future, and proposed policies for improving water resources and land productivity and managing the supply and demand of water, food and energy resources. Richardson et al. (2020) suggested in a study that investment in infrastructure development to improve agricultural productivity potentially plays a key role in the development of the agriculture sector. Mesgari et al. (2017) designed the dynamics of the agricultural development system in Iran and proposed policies for the productivity of water and land resources, considering the increase in demand and economic development in the future. There are also studies in agricultural entrepreneurship that focus on value creation and business creation in the agriculture sector.

After reviewing the agricultural development in Iran, Rezaei et al. (2017) emphasized entrepreneurial agriculture and recommended agricultural education oriented toward entrepreneurial goals and the generation of a non-traditional view. Rezaei and Izadi (2019) researched entrepreneurship obstacles in small agricultural quick-impact enterprises in Iran. Based on the results, management skills, knowledge management, business environment, self-managed training, and government policies predict changes in entrepreneurship development in quick-impact enterprises. Additionally, factor analysis indicated five obstacles in developing entrepreneurship in quick-impact enterprises, including financial problems, market orientation, weakness of information, poor and inappropriate business environment and weakness in supportive government policies. Kumar et al. (2021) identified sustainability and circular economy adoption barriers in the agriculture supply chain. The study indicates that lack of government support and incentives and lack of policies and protocols are significant obstacles .Yaghoubi et al. (2018) examined the effect of virtual social networks on the entrepreneurial behavior of agriculture students in Iran and emphasized the potential of virtual social networks in promoting the development of agricultural entrepreneurship in that country.

Zhu et al. (2019) addressed sustainable agriculture considering the development of entrepreneurship in China, and their findings indicated the substantial role of entrepreneurship in agricultural production in emerging economies. They also emphasized the role of financial incentives, information provision and technical support in developing entrepreneurship and proved the role of entrepreneurship in transforming government initiatives to improve the agriculture sector's economic and sustainable performance.

Wilkinson et al. (2017) investigated the organic agriculture policy as a context of institutional dynamics of entrepreneurship and considered the relationship between the structure and the concepts of entrepreneurship to develop organic agriculture policies and identify the areas of competition and distinct paths of institutional change under the influence of the interaction of entrepreneurship and institutional structural dynamics. Esiobu and Ibe (2015) analyzed the development of entrepreneurship in agriculture among farmers in Nigeria and discussed poor access to entrepreneurial information, insufficient seed capital and the long distance between farms and local markets as the main challenges of entrepreneurship development and called for support from the government and the private sector in order to develop agricultural entrepreneurship. Table 1 summarises a few studies conducted on sustainable entrepreneurship in Iran's agriculture sector.

Table 15. Literature on sustainable entrepreneurship in iran's agriculture sector

Researchers	Title	Findings
Najafabadi et al. (2021)	Water resources productivity and agricultural entrepreneurship development	Using water storage technologies and new irrigation technologies results in the development of entrepreneurship in the agriculture sector.
Heshmati et al. (2019)	Factors affecting sustainable development of agricultural entrepreneurship	The Ministry of Agriculture Jihad must pay more attention to the special role of its promotion and development forces to provide consulting and support services to farmers in order to develop agricultural businesses.
Hamidi et al. (2018)	Urban agriculture: A strategy for developing employment and entrepreneurship	Urban agriculture can attract a wide range of entrepreneurial employment opportunities in the production and agricultural services sector for the employment of agriculture graduates, which should be noted by employment and development authorities.
Ehsanifar et al. (2018)	Evaluation of the level of sustainability in agricultural entrepreneurial activities	Entrepreneurship units maintain a relatively stable state by observing indicators such as attention to natural resources, use of indigenous knowledge, use of low toxic chemicals, involvement and cooperation, communication with consulting centers, dependence on government support and subsidy, and the buyers' lack of awareness of the products.
Ahmadi et al. (2018)	Sustainable agricultural entrepreneurship of rural women	Social, marketing, policy-making, individual, psychological and technical components account for approximately 62% of changes in the variable of agricultural entrepreneurship capability.
Mirzaei and Sepah Panah (2018)	The effect of entrepreneurial characteristics of agricultural consulting services on entrepreneurial spirit	There is a significant relationship between the entrepreneurial spirit and a number of traits relevant to entrepreneurship, such as self-confidence, courage at work, teamwork, motivation and innovation, competitiveness, the rule of law and order, self-help, risk-taking, and job interest.
Sharifi et al. (2018)	Identification of sustainable agricultural development challenges	Protection-support, research-promotional, market-based and product-based factors were introduced as the most important obstacles and challenges on the path to sustainable agricultural development.
Morid Saadat and Eftekhari (2017)	Evaluation of sustainable agricultural development status with an entrepreneurial approach	The current status of sustainable agriculture with an entrepreneurial approach in Khuzestan is unfavorable, and the environmental dimension and the Mediterranean region are in worse conditions. Focusing on developing the environmental dimension and creating regional balance are emphasized.
Rasekhi et al. (2017)	Factors affecting the success of urban and rural agricultural entrepreneurs	There is a significant difference between urban and rural entrepreneurs in terms of individual resources, economic resources, political support and socio-cultural support, and the resources for the success of entrepreneurs in urban areas are more abundant than those in rural areas.
Rezaei et al. (2017)	Development of green entrepreneurship in line with promoting sustainable development	This study considered a simultaneous application of precision agriculture, organic agriculture and the production of healthy crops for reducing the use of chemicals, enhancing performance, increasing economic productivity and reducing adverse environmental effects.

Researchers	Title	Findings
Fallah Haghighi and Mirtorabi (2016)	Issues of knowledge-based agriculture companies located in the scientific and industrial research organization	Lack of trust in the market of knowledge-based agricultural products, lack of facilities and financial support from knowledge-based agriculture companies, poor administrative and legal structure in the establishment of knowledge-based agriculture companies, and inadequacy of supporting and commercializing policies and laws in the field of agricultural research.
Pay Khasteh et al. (2016)	Investigation of the competencies needed for the development of sustainable entrepreneurship	There are seven key dimensions involved in the formation of sustainable entrepreneurship development: Systems thinking, an integrated view of diversification and interdisciplinary thinking, insightful and normative thinking, interpersonal actions and strategic management

3. Methodology

According to the purpose of the research, the combined methodology of the fuzzy Delphi method and interpretive structural modeling (ISM) has been chosen. Key obstacles to sustainable agricultural entrepreneurship were identified in the first stage using a two-stage fuzzy Delphi. Table 2 presents the characteristics of the set of triangular fuzzy numbers, verbal expressions of the degree of influence and the used center of gravity de-fuzzification method.

Table 16. Fuzzy number set and the corresponding verbal expression and defuzzification method

Center of gravity	Rectangular fuzzy digits	Real number	Effectiveness rating
XM1 = (L1+M1+U1) / 3	X1 = (L1, M1, U1) = (0, 0, 0.25)	0	No effect
XM2 = (L2+2M2+U2) / 4	X2 = (L2, M2, U2) = (0, 0.25, 0.5)	1	Slight effect
XM3 = (L3+4M3+U3) / 6	X3 = (L3, M3, U3) = (0.25, 0.5, 0.75)	2	Low effect
Z* =MAX (XM1, MM2, MM2)	X4 = (L4, M4, U4) = (0.5, 0.75, 1)	3	High effect
X=((L1+L2+L3)/3, (M1+M2+M3)/3, (U1+U2+U3)/3)	X5 = (L5, M5, U5) = (0.75, 1, 1)	4	Very high effect

In the following, the matrix of effectiveness and effectiveness of key obstacles was compiled in the form of a questionnaire, and with the participation of experts, a structural self-interaction matrix was obtained. In the following, by forming the final matrix, the determination of relationships and leveling between obstacles was done, and finally, the network of interactions was designed as an interpretive structural model. Figure 1 presents the implementation process of the present research. The research participants were a combination of experts in sustainable agricultural development and entrepreneurship and management of active agricultural businesses in Iran. Table 3 shows the characteristics of the participants of this research.

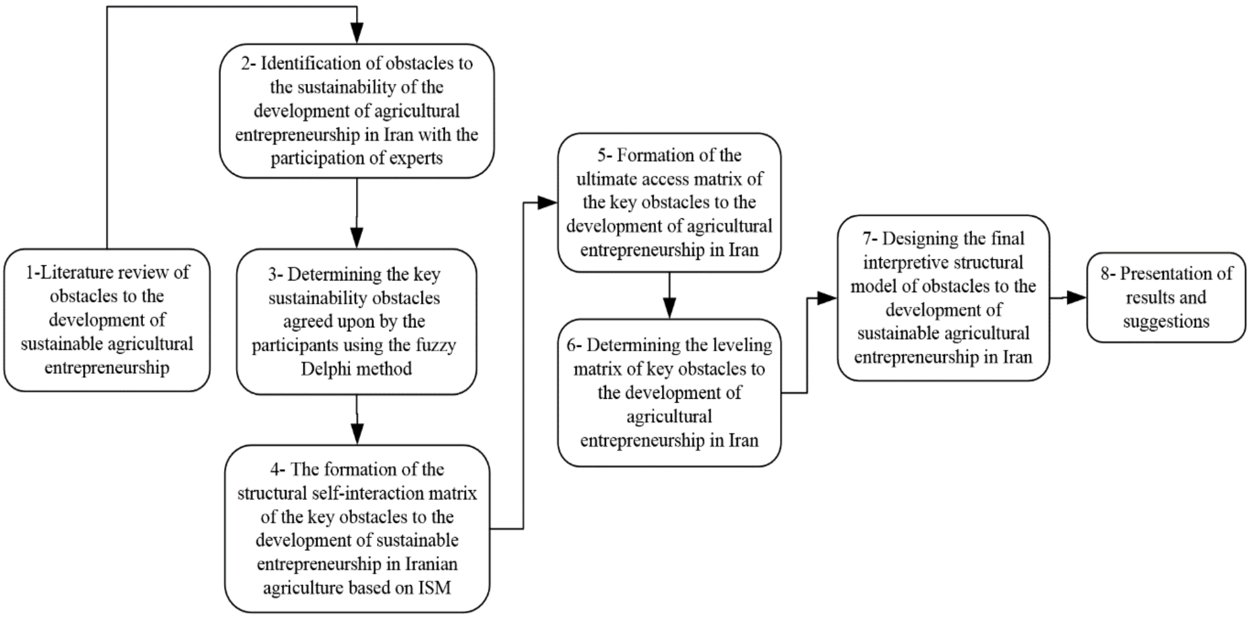

Figure 41. The implementation process of modeling the development of sustainable agricultural entrepreneurship in Iran

Table 17. Characteristics of research participants

Area of Expertise	**Experience (year)**	**Field**	**Education**
Entrepreneurial management	10<	Entrepreneurship	PhD
Investors of knowledge-based companies	15>	MBA Management	Masters
SME investor	20<	MBA Management	Masters
Agricultural development management	15<	Agricultural innovation and entrepreneurship	Masters
Entrepreneurial management	20<	Entrepreneurship	Masters
Agricultural entrepreneur	15<	Industrial Management	PhD
development of agricultural entrepreneurship	15<	Agricultural Engineering	PhD
Agricultural development planning	10<	agricultural development	PhD

4. Findings

According to the implementation process of the research, after reviewing the literature in the field of sustainable entrepreneurship in the agricultural industry and conducting semi-structured interviews with experts, a list of obstacles to the development of sustainable agricultural entrepreneurship was identified. As seen in Table 4, 41 obstacles, including 20 economic obstacles, 11 environmental obstacles and 10 social obstacles for developing agricultural entrepreneurship in Iran, were identified.

Table 18. Obstacles to sustainable entrepreneurship development in the agriculture sector

Sustainable dimensions	Symbol	Obstacles to sustainable entrepreneurship development in the agriculture sector	Reference
Economic (E)	E_1	Lack of sustainable entrepreneurship development strategies of the agriculture sector in the country's macro development plans	Experts' opinion
	E_2	Lack of investment in knowledge-based and technological entrepreneurship opportunities in the agriculture sector	Hosseinzadeh et al. (2022); Nguyen et al. (2021); Esiobu and Ibe (2015)
	E_3	Financing the agriculture sector dependent on the government banking system and government subsidies	Hosseinzadeh et al. (2022) Rezaei & Izadi (2019)
	E_4	Policymakers' lack of attention to sustainable management and development of agricultural entrepreneurship in line with environmental changes	Experts' opinion
	E_5	Failure to apply business consultants in identifying sustainable entrepreneurial opportunities in the agriculture sector	Hosseinzadeh et al. (2022); Nguyen et al. (2021); Heshmati et al. (2019)
	E_6	Incapacity of the administrative and legal structure in establishing knowledge-based companies in the field of agriculture and insufficiency of the policies and laws supporting and commercializing in the field of agricultural research.	Fallah Haghighi and Mirtorabi (2016)
	E_7	Shortage of loans and financial support for agricultural knowledge-based companies	Hosseinzadeh et al. (2022)
	E_8	Failure to formulate support policies for the emergence and commercialization of novel ideas in the agriculture sector	Hosseinzadeh et al. (2022); Zhu et al. (2019)
	E_9	Frustrating administrative bureaucracy for registering and confirming knowledge-based companies in the agriculture sector	Zhu et al. (2019)
	E_{10}	Absence of incentive policies to increase private sector involvement in providing capital to owners of sustainable entrepreneurial ideas in the agriculture sector	Hosseinzadeh et al. (2022); Rasekhi et al. (2017); Esiobu and Ibe (2015)
	E_{11}	Strict state regulations in approving agricultural knowledge-based products	Fallah Haghighi and Mirtorabi (2016)
	E_{12}	Failure to offer government loans to sustainable entrepreneurship in the agriculture sector to reduce investment risk	Hosseinzadeh et al. (2022); Zhu et al. (2019); Rasekhi et al. (2017)
	E_{13}	Failure to support the production-to-consumption chain and encourage sustainable entrepreneurship to improve the agriculture supply chain	Hamidi et al. (2018)
	E_{14}	High rate of bank interest for innovative agricultural plans	Fallah Haghighi and Mirtorabi (2016)
	E_{15}	Failure to consider the employment potential of the agriculture sector through sustainable entrepreneurship	Hamidi et al. (2018)
	E_{16}	Lack of product pricing systems, improper marketing, presence of brokers and consequently low profit for agricultural entrepreneurs	Hosseinzadeh et al. (2022); Sharifi et al. (2018)
	E_{17}	Absence or monopoly of distribution channels in the target markets of sustainable agricultural entrepreneurial opportunities	Hosseinzadeh et al. (2022); Nguyen et al. (2021)
	E_{18}	Failure to develop infrastructure suited to sustainable entrepreneurship opportunities in the agriculture sector	Richardson et al. (2020); Ehsanifar et al. (2018)

Sustainable dimensions	Symbol	Obstacles to sustainable entrepreneurship development in the agriculture sector	Reference
	E_{19}	Lack of proper agricultural support services offered by the Ministry of Agriculture Jihad to sustainable entrepreneurship in the agriculture sector	Heshmati et al. (2019)
	E_{20}	Failure to adopt appropriate policies to prevent smuggling and imports of similar products	Experts' opinion
Environmental (B)	B_1	Lack of knowledge about agricultural entrepreneurship opportunities in the optimization of cropping patterns and water consumption	Hosseinzadeh et al. (2022)
	B_2	Failure to consider entrepreneurship opportunities to develop infrastructural technologies of optimized water consumption in agriculture	Hosseinzadeh et al. (2022)
	B_3	Lack of knowledge about regional resources and opportunities for sustainable entrepreneurship of products suitable for the region's climate	Keyhanpour et al. (2021)
	B_4	Lack of knowledge relevant to using plant remains	Ehsanifar et al. (2018)
	B_5	Absence of binding laws to assure compliance with environmental standards in the agriculture sector	Experts' opinion
	B_6	Lack of development of new agricultural patterns, such as greenhouse cultivation	Keyhanpour et al. (2021)
	B_7	Failure to consider entrepreneurial opportunities of producing fertilizers based on compost to replace chemical fertilizers and other manure	Rezaei et al. (2017)
	B_8	Neglecting entrepreneurial opportunities in the area of packaging and post-harvest technologies and producing healthy products with few additives	Rezaei et al. (2017)
	B_9	Lack of knowledge about sustainable entrepreneurship opportunities to establish modern pressure irrigation technologies and the technology of GIS and remote sensing	Najafabadi et al. (2021)
	B_{10}	Neglecting entrepreneurial opportunities in the field of technologies and application of modern irrigation technologies	Najafabadi et al. (2021)
	B_{11}	Lack of knowledge about sustainable agricultural entrepreneurship in line with the climate of each region	Experts' opinion
Social (S)	S_1	Absence of formal education and creation of specialized knowledge for the development of sustainable entrepreneurship in the agriculture sector	Hosseinzadeh et al. (2022); Heshmati et al. (2019); Rezaei et al. (2017)
	S_2	Failure to promote society to create value and set up sustainable creative, and innovative businesses in the agriculture sector	Heshmati et al. (2019); Mirzaei and Sepah Panah (2018)
	S_3	Shortage of specialized consulting services in the area of sustainable entrepreneurship in the agriculture sector	Nguyen et al. (2021); Heshmati et al. (2019); Ehsanifar et al. (2018)
	S_4	Absence of trade unions and cooperatives in start-up and entrepreneurial businesses in the agriculture sector	Hosseinzadeh et al. (2022)
	S_5	Insufficient consideration of entrepreneurial R&D and little involvement of universities and research centers in research, training and promotion of sustainable agriculture	Hosseinzadeh et al. (2022)
	S_6	Failure to review and analyze successful international projects of sustainable entrepreneurship in the agriculture sector	Experts' opinion
	S_7	The low level of society's attention to the social responsibility of businesses	Experts' opinion
	S_8	The dominance of rural attitude in managing villages	Rezaei et al. (2017)
	S_9	Failure to cultivate entrepreneurial sustainable development competencies in the agriculture sector	Mirzaei and Sepah Panah (2018)
	S_{10}	Mistrust in the market of knowledge-based agricultural products	Fallah Haghighi and Mirtorabi (2016)

Then, based on the fuzzy Delphi method, the experts were asked to determine the effectiveness of obstacles in developing agricultural entrepreneurship by designing a questionnaire. After analyzing the data, as seen in Table 5, the expert group agreed upon 14 key obstacles, including 6 economic obstacles, 3 environmental obstacles and 5 social obstacles.

Table 19. Key obstacles to sustainable entrepreneurship development in the agriculture sector

Symbol	Key Obstacles of sustainable entrepreneurship development	Rate
E_1	Lack of sustainable entrepreneurship development strategies of the agriculture sector in the country's macro development plans	1
E_2	Lack of investment in knowledge-based and technological entrepreneurship opportunities in the agriculture sector	2
E_3	Financing the agriculture sector dependent on the government banking system and government subsidies	1
E_{10}	Absence of incentive policies to increase private sector involvement in providing capital to owners of sustainable entrepreneurial ideas in the agriculture sector	2
E_{16}	Lack of product pricing systems, improper marketing, presence of brokers and consequently low profit for agricultural entrepreneurs	7
E_{17}	Absence or monopoly of distribution channels in the target markets of sustainable agricultural entrepreneurial opportunities	6
B_1	Lack of knowledge about agricultural entrepreneurship opportunities in the optimization of cropping patterns and water consumption	4
B_5	Absence of binding laws to assure compliance with environmental standards in the agriculture sector	9
B_{11}	Lack of knowledge about sustainable agricultural entrepreneurship in line with the climate of each region	8
S_1	Absence of formal education and creation of specialized knowledge for the development of sustainable entrepreneurship in the agriculture sector	3
S_2	Failure to promote society to create value and set up sustainable creative, and innovative businesses in the agriculture sector	4
S_3	Shortage of specialized consulting services in the area of sustainable entrepreneurship in the agriculture sector	5
S_4	Absence of trade unions and cooperatives in start-up and entrepreneurial businesses in the agriculture sector	10
S_5	Insufficient consideration of entrepreneurial R&D and little involvement of universities and research centers in research, training and promotion of sustainable agriculture	3

According to the interpretative structural methodology, the experts were invited to study the effective barriers in pairs using the symbols below.

V: One-way communication from i to j
A: One-way communication from j to i
X: Two-way communication between i and j
O: There is no connection between i and j

Based on this comparison, the structural self-interaction matrix was set (Table 6), and in the next step, the reachability matrix was obtained (Table 7). The adapted reachability matrix was obtained in the following, taking into account transferability in the relationships of the variables (Table 8).

Table 20. The structural self-interaction matrix (SSIM)

	S_5	S_4	S_3	S_2	S_1	B_{11}	B_5	B_1	E_{17}	E_{16}	E_{10}	E_3	E_2	E_1
E_1	X	O	O	O	V	V	V	V	O	O	V	V	V	
E_2	A	A	A	A	A	A	A	A	A	A	A	A		
E_3	X	V	X	V	V	V	V	V	V	V	V			
E_{10}	A	A	A	A	X	X	X	V	V	0				
E_{16}	A	A	A	A	A	O	O	O	O					
E_{17}	A	A	A	A	O	X	O	O						
B_1	A	O	A	A	A	A	A							
B_5	V	V	V	V	V	V								
B_{11}	A	A	A	X	A									
S_1	A	O	A	X										
S_2	A	A	A											
S_3	V	A												
S_4	V													
S_5														

Table 21. The reachability matrix

	S_5	S_4	S_3	S_2	S_1	B_{11}	B_5	B_1	E_{17}	E_{16}	E_{10}	E_3	E_2	E_1
E_1	1	0	0	0	1	1	1	1	0	0	1	1	1	1
E_2	0	0	0	0	0	0	0	0	0	0	0	0	1	0
E_3	1	1	1	1	1	1	1	1	1	1	1	1	1	0
E_{10}	0	0	0	0	1	1	1	1	1	0	1	0	1	0
E_{16}	0	0	0	0	0	0	0	0	0	1	0	0	1	0
E_{17}	0	0	0	0	0	1	0	0	1	0	0	0	1	0
B_1	0	0	0	0	0	0	0	1	0	0	0	0	1	0
B_5	1	1	1	1	1	1	1	1	0	0	1	0	1	0
B_{11}	0	0	0	1	0	1	0	1	1	0	1	0	1	0
S_1	0	0	0	1	1	1	0	1	0	1	1	0	1	0
S_2	0	0	0	1	1	1	0	1	1	1	1	0	1	0
S_3	1	0	1	1	1	1	0	1	1	1	1	1	1	0
S_4	1	1	1	1	0	1	0	0	1	1	1	0	1	0
S_5	1	0	0	1	1	1	0	1	1	1	1	1	1	1

Table 22. The adapted matrix

		S_5	S_4	S_3	S_2	S_1	B_{11}	B_5	B_1	E_{17}	E_{16}	E_{10}	E_3	E_2	E_1	
		14	13	12	11	10	9	8	7	6	5	4	3	2	1	Σ
E_1	1	1	0	0	0	1	1	1	1	0	0	1	1	1	1	9
E_2	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
E_3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1^*	14
E_{10}	4	1^*	0	0	0	1	1	1	1	1	0	1	0	1	0	8
E_{16}	5	0	0	0	0	0	0	0	0	1^*	1	0	0	1	0	3
E_{17}	6	1^*	0	0	1^*	0	1	0	1^*	1	1^*	1^*	0	1	0	8
B_1	7	0	0	0	0	0	0	0	1	0	0	0	0	1	0	2
B_5	8	1	1	1	1	1	1	1	1	0	0	1	1^*	1	1^*	12
B_{11}	9	0	0	0	1	1^*	1	1^*	1	1	0	1	0	1	0	6
S_1	10	0	0	0	1	1	1	0	1	0	1	1	0	1	0	7
S_2	11	0	0	0	1	1	1	0	1	1	1	1	0	1	0	8
S_3	12	1	0	1	1	1	1	0	1	1	1	1	1	1	0	11
S_4	13	1	1	1	1	0	1	1^*	0	1	1	1	0	1	0	10
S_5	14	1	1^*	1^*	1	1	1	0	1	1	1	1	1	1	1	13
	Σ	8	4	5	9	9	11	6	11	9	8	11	5	14	4	

The input and output sets of each variable were obtained with the help of the matrix. The variables whose output and common sets were completely similar were placed at the highest level of the interpretive structural mode hierarchy. This operation was repeated until the components of the subjects of all levels were determined. Table 9 provides the ratings of the barriers to sustainable entrepreneurship development in the agriculture sector.

Table 23. The rating matrix of the barriers to sustainable entrepreneurship development in the agriculture sector

Barriers	Input Set	Output Set	Common Set	Level
E_1	1,3,8,10,14	1,2,3,4,7,8,9,10,14	1,3,8,10,14	Level 5
E_2	1,2,3,4,5,6,7,8,9,10,11,12,13,14	2	2	Level 1
E_3	1,3,8,10,12,14	1,2,3,4,5,6,7,8,9,10,11,12,13,14	3,8,10,12,14	Level 5
E_{10}	1,3,4,6,8,9,10,11,12,13,14	2,4,6,7,8,9,10,14	4,6,8,9,10,14	Level 3
E_{16}	3,5,6,10,11,12,13,14	2,5,6	5,6	Level 2
E_{17}	3,4,5,6,9,11,12,13,14	2,4,5,6,7,9,11,14	2,4,5,6,9,11,14	Level 3
B_1	1,3,4,6,7,8,9,10,11,12,14	2,7	7	Level 2
B_5	1,3,4,8	2,4,7,8,9,10,11,12,13,14	4,8	Level 4
B_{11}	1,3,4,6,8,9,10,11,12,13,14	2,4,6,7,8,9,10,11,12	4,6,8,9,10,11,12	Level 3
S_1	1,3,4,8,10,11,12,14	2,4,5,7,9,10,11	4,10,11	Level 4
S_2	3,6,8,9,10,11,12,13,14	2,4,5,6,7,9,10,11	6,8,9,10,11	Level 3
S_3	3,8,9,12,13,14	2,3,4,5,6,7,9,10,11,12,14	3,8,9,12,14	Level 5
S_4	3,8,13,14	2,4,5,6,8,9,11,12,13,14	8,13,14	Level 5
S_5	1,3,4,6,8,12,13,14	1,2,3,4,5,6,7,8,9,10,11,12,13,14	1,3,4,6,8,12,13,14	Level 5

Finally, a preliminary model was drawn according to the variables' levels and the final researchability matrix. As illustrated in Figure 2, the final model of the interpretive structure was drawn by removing transferability in the preliminary model.

It can be seen that the barriers to sustainable entrepreneurship development in the agriculture sector have been identified. At the fifth level, the absence of strategies for sustainable entrepreneurship development in the agriculture sector in the country's macro development plans, the dependence of the financing of the agricultural sector on the government banking system and government subsidies, lack of specialized consultants in the area of sustainable entrepreneurship in the agriculture sector, lack of trade unions and cooperatives in start-up and entrepreneurial businesses in the agriculture sector, insufficient consideration of entrepreneurial R&D and little involvement of universities and research centers in research, training and promotion of sustainable agriculture were identified. This indicates the high impact of these barriers on the path toward the realization of sustainable entrepreneurship in the agriculture sector. At the fourth level, the absence of binding regulations to assure compliance with environmental standards in the agriculture sector and the lack of formal education and creation of specialized knowledge for the development of sustainable entrepreneurship in the agriculture sector were considered to affect the factors of the third level, namely absence of incentive policies to increase private sector involvement in providing capital to owners of sustainable entrepreneurial ideas in the agriculture sector, lack of knowledge about sustainable agricultural entrepreneurship in line with the climate of each region, absence of distribution channels in the target markets of sustainable agricultural entrepreneurial opportunities and monopoly of distribution units, as well as failure to promote the society to create value and start sustainable, innovative businesses in the agriculture sector. Moreover, at the second level lies the lack of knowledge about agricultural entrepreneurship opportunities in optimizing cropping patterns and water consumption, lack of product pricing systems, improper marketing, presence of brokers and consequently low profit for agricultural entrepreneurs. At the first level, lack of investment in knowledge-based and technological entrepreneurship opportunities in the agriculture sector was identified as the most susceptible barrier to the realization of sustainable entrepreneurship in the agriculture sector.

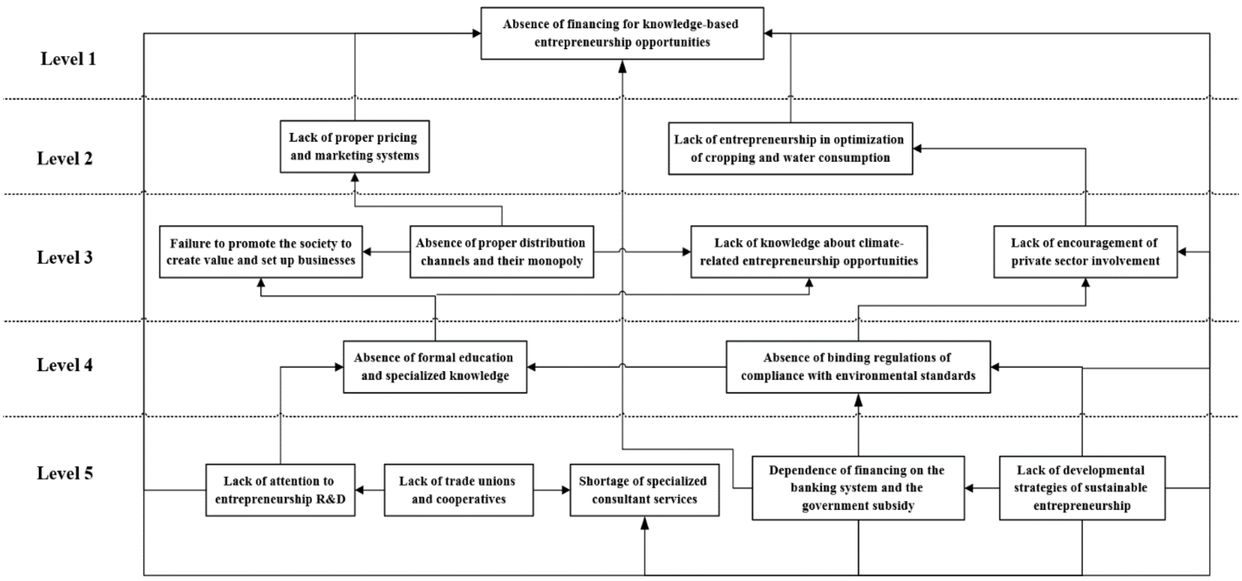

Figure 42. The interpretive structural model of the barriers to sustainable entrepreneurship development in the agriculture sector

5. Discussion and conclusion

Sustainable agriculture, as the central axis of sustainable development, has been known as an appropriate approach toward economic sustainability and attention to the lives of a significant third-world population. Sustainable agricultural development rests on the notion that agricultural methods not only at the level of food production but also, to a large extent, at the level of environmental conditions influence the capacity of agriculture in sustainable use of varied ecosystem services. Sustainable agriculture is considered an approach to ensure economic, social and ecological sustainability. Given the capacities of developing agriculture entrepreneurship in Iran, it is vital to use the entrepreneurship capability to address sustainable development. This is named sustainable entrepreneurship. Sustainable entrepreneurs focus on identifying new business opportunities that lead to developing products or processes that are more sustainable than currently available in the market. After reviewing the literature and consulting the experts in entrepreneurship development and sustainable agricultural development, this study proposed an interpretive structural model to identify the barriers to developing Iran's sustainable agricultural entrepreneurship. Based on the model's findings, an interrelationship diagram of the obstacles to sustainable agricultural entrepreneurship development was designed at five levels. At the fifth level, the fundamental obstacles include a lack of sustainable agricultural entrepreneurship development strategies in the country's macro development plans, the dependence of the financial resources of the agricultural sector on the government banking system and government subsidies, shortage of sustainable agricultural entrepreneurship consulting services, and insufficient attention to research and development and little participation on the part of universities and research and education institutes toward the promotion of sustainable agriculture. This is indicative of the immense impact of such obstacles on the trajectory to the realization of sustainable agricultural entrepreneurship. At the fourth level, there is a lack of binding laws to assure compliance with environmental standards and a lack of formal training and specialised knowledge creation. The third level includes a lack of incentive policies to increase private sector involvement in providing capital for owners of sustainable agricultural entrepreneurship ideas, a lack of recognition of sustainable agricultural entrepreneurship opportunities in line with the region's climate, a lack of distribution channels in the target markets of sustainable agricultural entrepreneurship opportunities, and lack of social development toward creating values and establishing innovative and creative sustainable agricultural businesses. At the second level, there is a lack of knowledge on agricultural entrepreneurship opportunities in optimizing cultivation and water consumption patterns, a lack of product pricing systems, and improper marketing. Eventually, at the first level, a lack of investment in knowledge-based and technological entrepreneurship opportunities in the agricultural sector has been identified as the most susceptible obstacle to realizing sustainable agricultural entrepreneurship. Analysis of the barriers to development was an attempt to enhance the understanding and cognition of agricultural sustainable entrepreneurship development policy-makers and planning for developing sustainable agricultural entrepreneurship.

In future research, it is suggested that the causes and factors affecting Iran's sustainable agricultural entrepreneurship ecosystem be analyzed based on the new theories in this field. It is also suggested that to remove the obstacles, each obstacle's main actors and stakeholders should be identified, and the system solutions agreed upon by the stakeholders should be extracted using soft systems methodology. The design of the system dynamics model is also suggested in future research to identify sustainable entrepreneurship development policies in Iran's agriculture.

Disclosure statement

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

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