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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 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 1. 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 2. 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	+
(Pereira-Moliner, et al., 2012)	Quality management, environmental management and firm performance: direct and mediating effects in the hotel industry	Structural equation	+

Authors Name	Article Name	Type	Relation
(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.

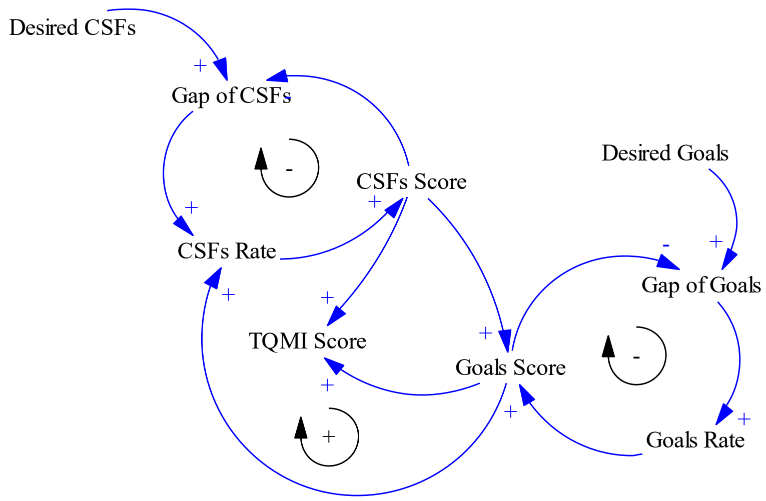


Figure 1. The dynamic hypothesis of the study

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:

$$g_j(x_1, x_2, ..., x_n) = q_0 + q_1 x_1 + ... + q_n x_n \tag{2}$$

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*).

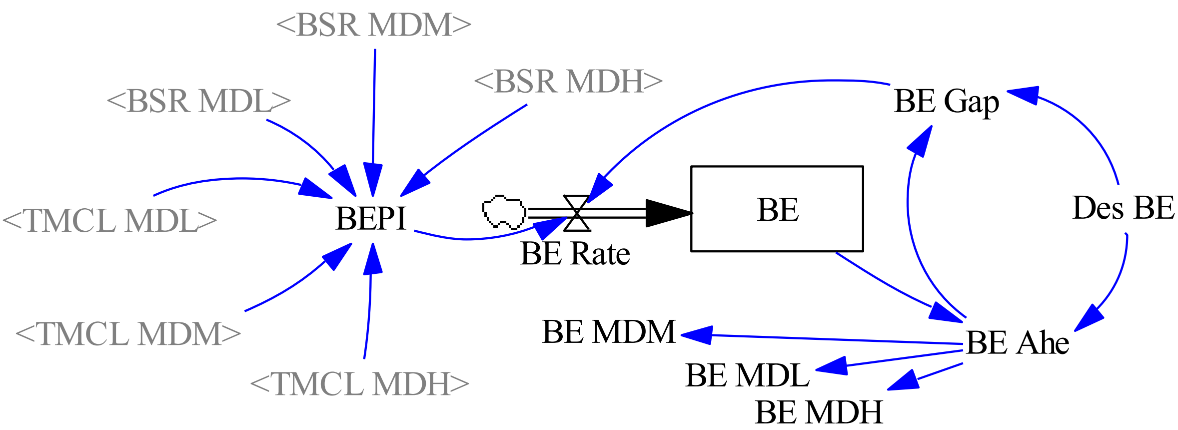


Figure 2. The sampling variable stock-flow diagram

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.

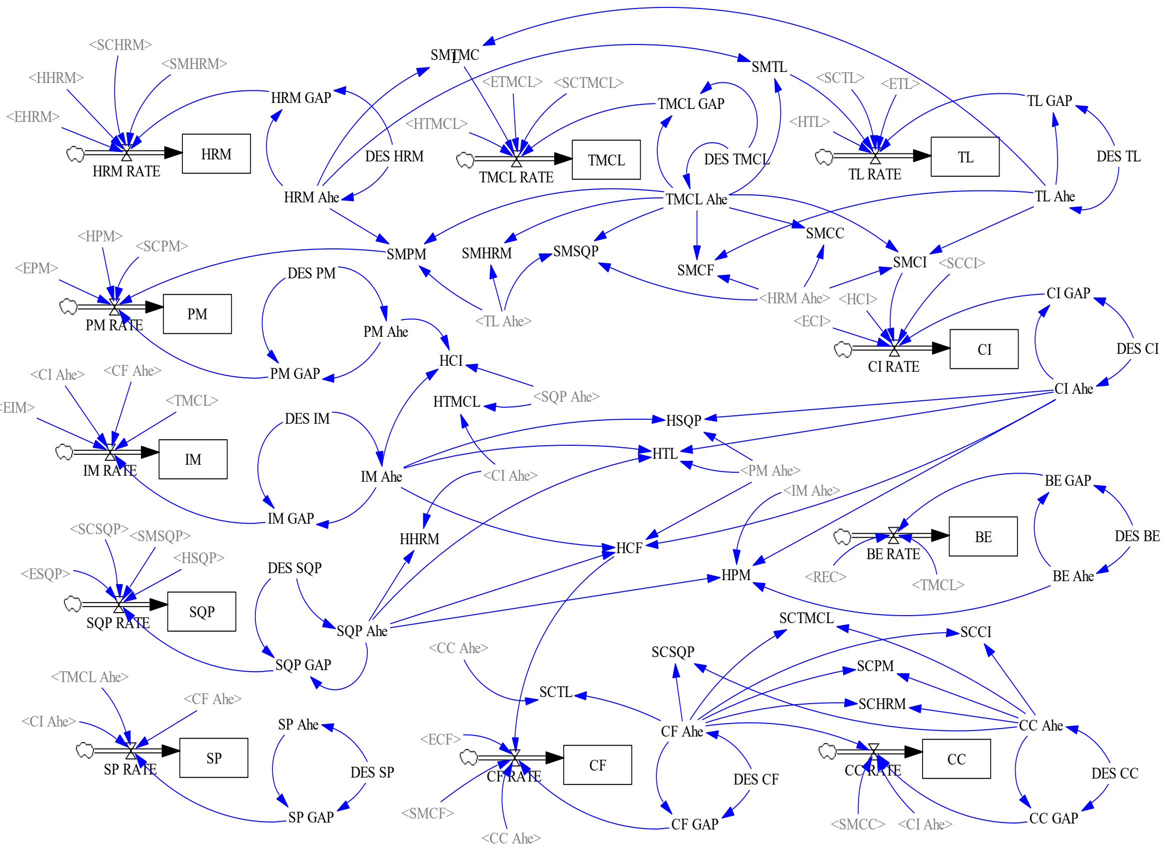


Figure 3. The stock-flow diagram of the key success factors of total quality management

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

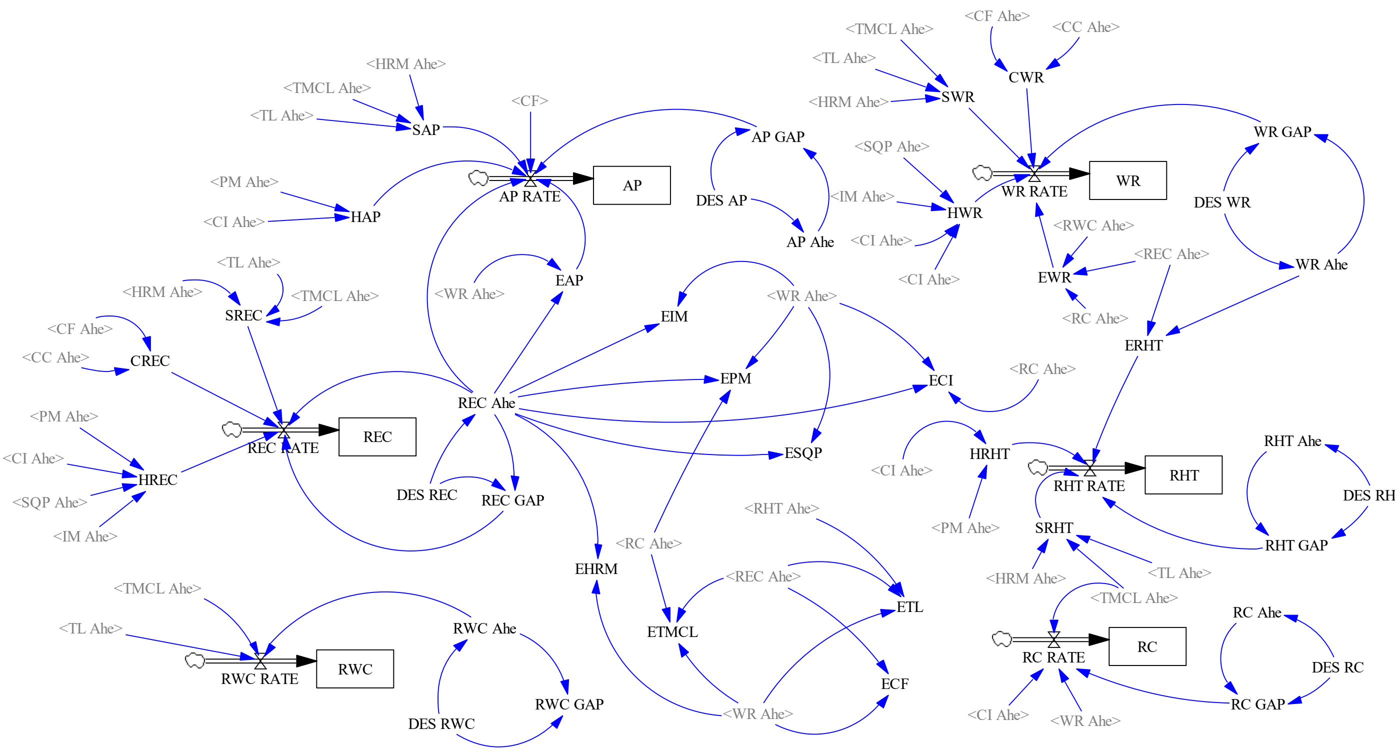


Figure 4. The calculation of the environmental index

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

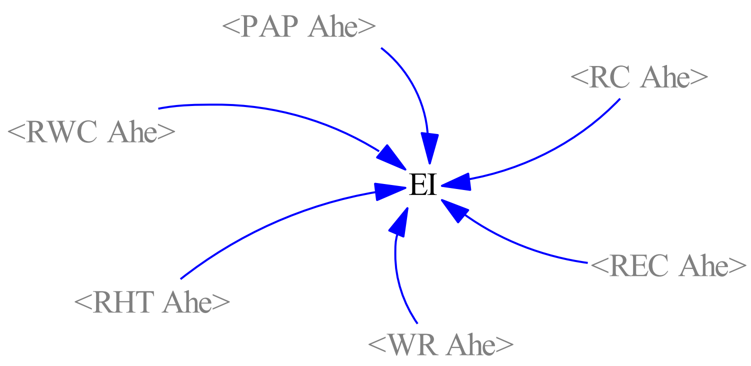
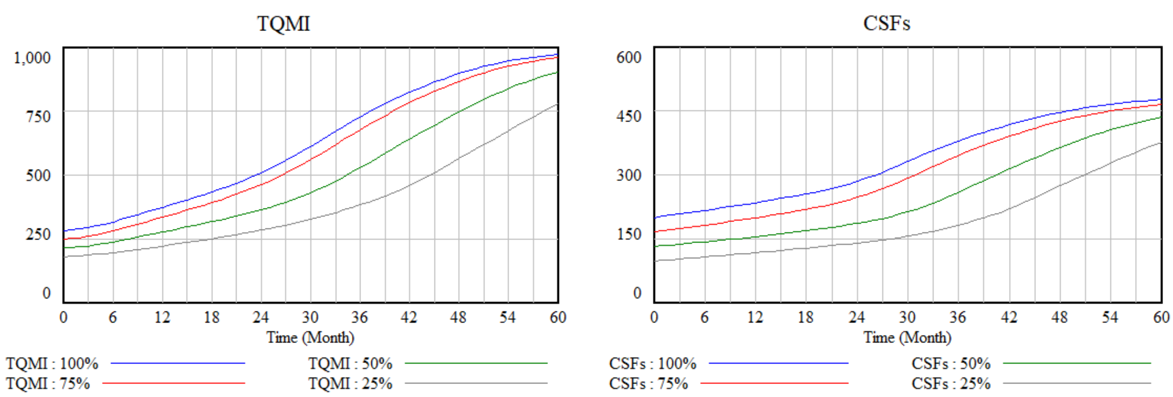


Figure 5. The calculation of the environmental index

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

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 3. 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.

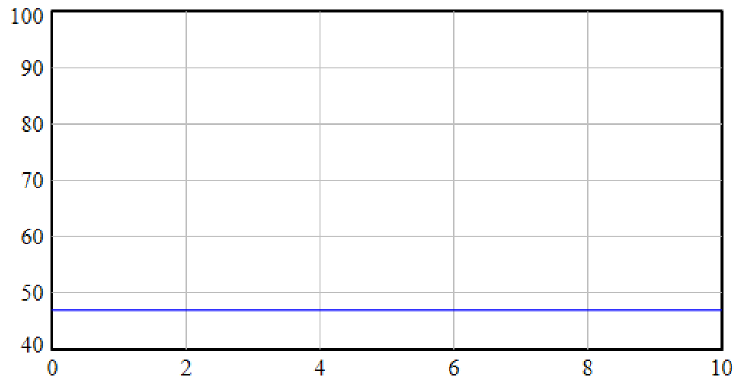


Figure 7. The behavior of the EI variable in the limit condition of zeroing the input rate of the state variables

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.

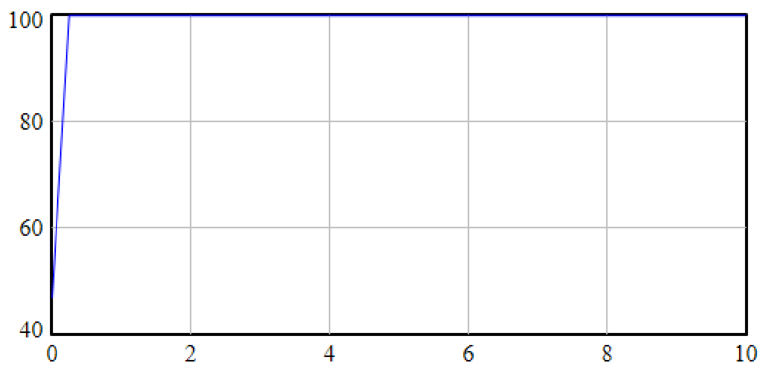


Figure 8. The behavior of the EI variable, in the limit condition of ten thousand times the input rate of state variables

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.

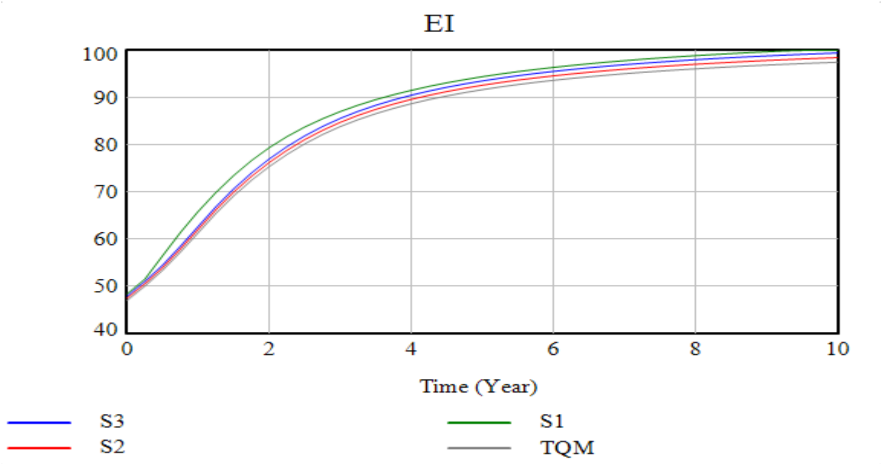


Figure 9. Simulation results of study policies

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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