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Review

An Integrated Knowledge Management Framework for Sustainable Supply Chain Using a System Dynamics Model for POGC

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ABSTRACT

Supply chains have experienced rapid growth in recent years. Focusing purely on economic performance so as to optimize costs or return on capital can no longer guarantee development or sustainability in the chain. Hence, the concepts of green supply chain management and sustainable supply chain management emerged to emphasize the importance of social and environmental concerns along with economic factors in supply chain programming. Using the system dynamics method and considering knowledge management, this study investigates the variables related to this topic and the variables of sustainable supply chain management, and it determines the relationships between these variables and their impact on the research purpose. To achieve this, first, previous studies are reviewed, and the relevant variables are extracted and finalized according to the experts. Next, a system dynamics model is designed, and various scenarios are defined by changing the effective values of the system. Eventually, several policies are presented to achieve the optimal situation. The optimal values of the ten main influential variables are extracted according to the expert opinion, and the effects revealed by the model are determined by these changes.

1. Introduction and Literature Review

Globalized economic systems involve complex supply chains, including environmental and social impacts on stakeholder's expectations and the reduced risks of manageable sustainability (Hendalianpour et al., 2019). Quantitative modeling approaches to sustainable supply chain management (SSCM) have been recently the subject of intense research. Unlike analytical models and mathematical programming, simulation methods are not used in SSCM. In another work, Nabavi et al. (2017) emphasized the need for the development of the world as a complex system to deal with complex problems in a society in which we understand that "one aspect cannot be considered and all aspects are interconnected". There

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are various schools of thought and practical areas of systematic thinking, including qualitative methods and formal SD modeling. Researchers have shown that SD is a technique for modeling and simulating complex systems, including the relationships between economic, environmental, and social variables in relation to social action to discover alternative pathways of evolution. For the first time, SD was used to investigate the dynamics of production-distribution systems (Rebs et al., 2019).

Sustainable intra-organizational supply chain management in a unique company and inter-organizational one between two or more agents are key the components of economic systems which are built and controlled by social systems and utilize environmental system resources (Liu et al., 2019). Due to the limited environmental/natural resources and the growing world population, sustainable supply chain management has become a growing concern because production and logistics activities consume existing resources and increase waste and pollution (Shafique et al., 2019). In addition, human working conditions and other social factors often cause stress, especially if the benefits of dispersed distribution are obvious (Morgan et al., 2017).

In the current work, dynamics system modeling (DSM) is used to model the factors affecting the sustainable supply chain. Since this approach considers both the factors influencing the sustainable supply chain and their interactions, the results are well-validated. For this purpose, previous studies are reviewed, and the variables effective on the sustainable supply chain and the variables related to the knowledge management (KM) which influence the supply chain are extracted according to the experts' point of view. Then, the SD model was designed, validated, and evaluated using Vensim software. Finally, five scenarios for decision making are presented and reviewed.

Sustainability management is defined as strategic business activities to minimize environmental, economic, and social sustainability risks, which maximize corporate value, including shareholder value (Wong et al., 2014), (Tseng et al., 2009).

Feitó-Cespón et al. (2017) presented a model considering the uncertainties in demand and suppliers of recycled products in reverse logistics redesign. In another study, Alayet et al., 2018 examined logistic approaches to better coordinate forest product supply. Rafie-Majd et al. (2018) presented a three-tiered supply chain, including suppliers, some distribution centers, and some retailers (customers) as an inventory-locating-routing problem. Mogale et al. (2017) presented a new multi-periodic, multi-model, and multi-objective mathematical model for the locating-allocation problem of time-resolved bean silage to support the decision-making process of the Indian government. Dai et al. (2018) integrated supply for perishable products with fuzzy capacity and carbon emission and therefore improved it with the optimization model.

Khodaparasti et al. (2018) introduced a multi-periodic location-allocation problem for reverse supply chain network programming. Doolun et al. (2018) formulated a multi-objective mathematical model to solve the allocation problem in a multi-echelon supply chain network. Using this model, they optimize three objectives, namely total supply chain cost minimization (TSCC), filler rate maximization, and CO_2 emission minimization. Vafaeinezhad et al. (2016) proposed a multi-objective linear programming model for a multi-product multi-periodic supply chain programming. Alinaghian and Zamani (2019) offered a new two-objective model for the problem of heterogeneous fleet green inventory routing. Banasik et al. (2019) proposed a two-stage stochastic programming model for analyzing and evaluating economic and environmental impacts on uncertainty in food supply chains. Considering the multi-purpose, multi-product, multi-periodic procurement time, Niu et al. (2019) developed a realistic integrated supply chain model. Manupati et al. (2019) investigated various production-distribution and inventory issues in the multilayer supply chain with three policies in carbon and leadership time considerations. Mohammed and Duffuaa (2019) introduced a new solution based on a simulated annealing algorithm to obtain near-optimal solutions for multi-purpose supply chain design problem. Badhotiya et al. (2019) tackled an integrated production and distribution programming problem for a two-tier supply chain network consisting of multiple manufacturers serving in multiple sales locations. Cao et al. (2019) proposed a CO_2 emission estimation model from the direct cost prospect and then developed an SD model to simulate CO_2 emission reduction scenarios throughout the life cycle of the green electric coal supply chain.

Based on previous literature, the lack of quantitative results from the combination of KM and supply chain is quite clear. Most studies in this context have merely demonstrated the strength of a chain by using a descriptive and interpretive supply chain and have not yielded any further results. In this study, we proceed step further and design a supply chain using KM. The innovations of the current work are as follows:

- Using KM to design sustainable supply chains.
- Using the SD method to model knowledge gained from KM.
- Analyzing and modeling SDs to meet cost minimization goals and environmental pollutions and satisfy social responsibilities.
- Implementing the proposed model for National Iranian Oil Company (NIOC).

With due attention to previous studies, the compound method proposed herein is incomparable in the literature on the subject.

2. Methodology

Systematic approaches use system-based thinking patterns. The method was developed in 1950 at Massachusetts Institute of Technology (MIT) by Forrester and was used in electrical engineering studies. The method predicts system behavior based on the relationships between system components, and these patterns are a way to understand the behavior of complex systems over time (Bagheri et al., 2015). What distinguishes the SD method from other methods is the use of feedback loops and flow and state variables which help understand the behavior of the system. This approach is based on the understanding that the structure of the system, including nonlinear relationships, delays, and the feedback is important in determining the behavior of the system because it recognizes the individual components (Sosnowska et al., 2019). It is also claimed that there are properties in the whole system which cannot be found in any single element, and, in some cases, the behavior of the whole system cannot be explained by the behavior of its components. This method is the result of a kind of approach to dynamic systems that is used to develop the boundaries of mental models and to drive a tool to understand how the structure of a complex system generates its behavior (Nguyen et al., 2017).

By expanding and intensifying the competitive environment in today's world, the optimal design of a sustainable supply chain has become one of the fundamental issues which businesses face, which affects all organizational activities to manufacture products, improve quality, reduce costs, provide the services required by customers, and minimize the environmental damage. Over the past few decades, the world has experienced rapid economic growth due to the advances in new technologies, the globalization of the economy and financial and credit resources, the expansion of global markets, and the facilitation and acceleration of the production factors. However, economic growth has caused severe environmental problems such as water, soil and air pollution, ozone depletion, rapid deforestation, global warming, and acid rain, the majority of which stem from the industrial sections. Therefore, decision-makers in industries such as oil refining and their decisions play an important role in preventing environmental damage (Moretto et al., 2019).

With increasing greenhouse gas emissions and pollutants, organizations and researchers are looking to design and operate sustainable networks which focus on both economic optimization and environmental factors and pollutant reduction in all sectors. Today, many countries are increasingly paying attention to environmental protection and environmental laws. Therefore, industry owners and manufacturers have been attracted to supply chain design and development with respect to environmental factors (Hussain et al., 2018).

This study uses the SD method to design sustainable supply chains considering knowledge management indices so as to optimize environmental costs and impacts and increase social satisfaction. Desktop data, i.e. articles, books, and existing documents, were used to gather the information needed for this research. Consultation with academic and operational experts can also be used to complete the required information circle. Given the importance of the subject, it is a good strategy to employ new tools to improve productivity. To the best of our knowledge, in previous studies, this problem was more descriptive and interpretative, and it was tried to optimize the supply chain using different methods. Accordingly, in this study, we offer a combination of powerful models that examine various influencing factors and consider SD over time using the scientific principles which can be of great help to decision-makers. Then, we describe each step of the proposed model in detail.

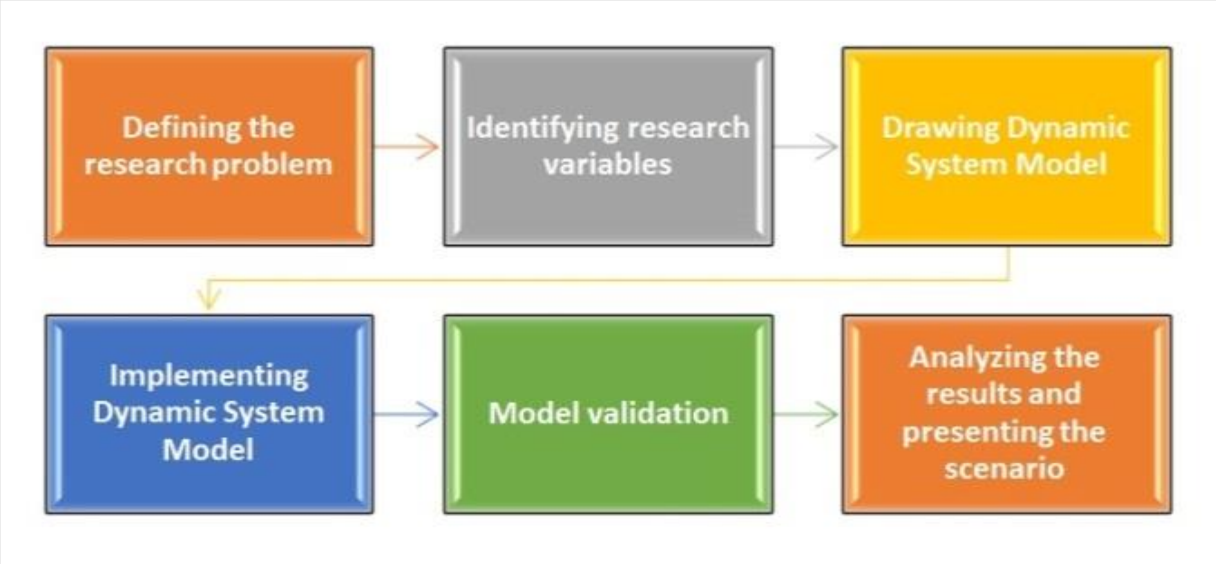

Figure 1. Implementation steps of the current research.

2.1. Defining the Research Problem by Examining the Background

This step involves identifying the nature of the problem and defining the problem. The first part of the problem solving may seem obvious; however, it often requires thought and analysis. Problems can be a bit difficult to identify because one may ask whether there is a problem at all. What is the nature of the problem? How many issues are there? How can that be defined? When the problem is properly defined, not only it is better understood, but also its nature can be discussed with others, as the second step of this research (Blom, n.d.). In this regard, an incorrect definition of the problem will lead to incorrect modeling and, consequently, false results.

2.2. Identifying the Research Variables

A variable is any measurable attribute that varies from person to person. Variables are attributes of individuals, objects, units, etc. which can take quantitative or qualitative values. Among the quantitative values, we can mention height, weight, and IQ. Factors such as satisfaction and loyalty are among the qualitative variables. After defining the problem and setting goals, the research variables or criteria affecting the research problem are identified. Identifying the main groups and the corresponding subgroups can help determine these criteria precisely. The criteria influencing the system under review are first collected by reviewing previous literature and then finalized by consulting with a panel of selected experts. In order to better clarify and elaborate on this step, we can rephrase the abovementioned sentences in detail as follows. Due to the study gap and the lack of a relationship between sustainable supply chain and knowledge management in the previous studies, the present study takes into account designing a sustainable supply chain using the variables affecting knowledge management and modeling the knowledge resulting from knowledge management using system dynamics method. To collect the required data, articles, libraries, and the experts' opinions on this subject based on operational data were utilized. At first, all the influencing variables were supplied by oil companies specifically supply chain specialists in Pars Oil and Gas Company (POGC). Then, the extra variables were removed and the essential ones were added based on the experts' opinions. In total, 50 effective variables and indices were determined. To extract the final economic, social, environmental, and knowledge socio-management criteria, 15 individuals from supply chain specialists in purchasing, procurement, construction, and project units of the company with at least a bachelor's degree and 15 years of useful work experience in the related field participated in the discussing session through focus group method and scored the 50 final variables in terms of the performance (0-9); then, the variables were ranked; ultimately 11 variables with a score of 27 and higher were eliminated, and 39 key variables and final indices were confirmed for the final system dynamics model.

2.3. Developing a Dynamic System Model

At this stage, the dynamic system model is developed using the result of the previous step and the list of variables affecting the system. The research question, i.e. the sustainable supply chain system analysis, is placed at the center and the effect of the metrics defined in step two on the research question and their interactions are examined. The research problem is referred to along with the criteria affecting it as concepts (nodes) and the relation between the criteria as arcs. The dynamic system model created specifies the causal relationships between the concepts. One or more concepts are considered as state variables, and one or more concepts are considered as rate variables. The state variables result from the accumulation of the rate variables (Tao et al., 2018)(Xiu et al., 2019). At this stage of the dynamic system implementation, the following steps must be performed as well.

2.4 Modeling Time Horizon

Choosing the right time horizon is critical to the analysis of the model results. Time horizons are usually short-lived cause-and-effect loops, while the effects of loops are long-term learning and feedback. Hence, it is important to balance the time horizon.

Formulating dynamic model hypotheses: A dynamic hypothesis is an efficient theory of how a problem arises. The dynamic hypothesis explains the causes of the problem observed in the reference patterns. It constantly learns about the modeling process and the real world that are subject to modification or rejection. Investigating the criteria which affect different groups and consulting with experts may have some impact on the sustainable supply chain analysis. Furthermore, by drawing a general model that incorporates all influential groups, new relationships between variables may be created, or some of the recurring factors in the groups are eliminated.

Determining the boundary **of the model:** Precise model constraints are the essential components of the system. However, the dynamic system helps expand the boundaries of mental models.

Research model loops: the proposed model is developed using explicit and hidden cause and effect relationships. All the factors investigated locally and through foreign studies are reviewed. According to experts, by eliminating similar cases, comprehensive groups are achieved. The depicted simulated model is run in the next step

2.5. Running the Dynamic System Model in Vensim Software Environment

The dynamic system is implemented by transferring the model designed for the research problem to the Vensim software. In this software, for each arc, one can determine whether the effect applied from one concept to another is either positive (incremental) or negative (decremental). Each concept is formulated based on the concepts affecting it. In a dynamic system, except for variables or concepts that have a formal and fixed definition (e.g., income = price × unit of product sold), a set of formulas and equations are defined for other (quantitative or qualitative) concepts so that their form and effect are logical after executing the program. For example, if prices drop, demand is expected to rise. This step is performed based on a trial and error approach, which is more complex for qualitative variables. After formulating all the concepts, the model is run in Vensim software environment. The implementation of the model determines what the variables/values look like in the set time horizon.

2.6. Model Validation

Model is validated to clarify whether the research variables and the relationship between them are correctly determined. The system consisting of these variables and their relationships is examined by a series of tests which will be explained to satisfy the standard model created by the dynamic system model.

2.7. Results Analysis and Scenario Presentation

At this step, the results of implementing the simulated model with the present data are specified, and the optimal conditions of the system are determined by defining a scenario which combines modes of change in variables. In this way, optimizing changes can overcome system failures.

3. Case Study

The study site is a gas refinery in South Pars gas filed, and the refinery can be divided into three main sections, which are described in detail in the following:

- The offshore section of the project consists of two offshore gas platforms 105 kilometers from Asaluyeh; both platforms comprise 12 main loops for production.
- The section of marine gas transmission to the refinery also includes two 32-inch pipelines for

transferring sour gas to the shore and two 4-inch pipelines for transferring ethylene glycol solution to the well head facilities.

- The onshore project section also comprises a refinery for sour feed gas refining, including gas receiving; dehydration; sweetening; ethane, propane, and butane refining; condensate stabilization; glycol recovery; sulfur production; and granulation. Finally, the produced gas is sent to the national gas pipelines.

3.1. Defining the Research Problem by Examining the Background

A sustainable supply chain is a system of organizations, people, activities, information, and resources involved in transferring a product or service from supplier to customer, taking into account economic, social, and environmental factors. In general, supply chain activities convert natural resources, raw materials, and components into the final product to be delivered to the customer (Marra et al., 2012). Creating a sustainable supply chain and trying to maximize the benefits of the whole chain is essential for survival and success in today's markets. By forming a network of organizations and operating within a sustainable supply chain, manufacturers, suppliers, distributors, warehouses, retailers, and customers seek to ensure expanding them in global markets so as to meet the ever-increasing needs of customers. As a result, organizations work together toward common goals (Sambasivan et al., 2009).

Sustainable supply chain management has become one of the topics of interest in the last decade for several reasons (Koberg and Longoni, 2019):

- Today, a few companies are still vertically organized, and companies have become more specialized. Instead of supplying their resources, they are looking for suppliers who can supply high-quality raw materials at low prices.
- Competition has been intensified at national and international levels. Customers have many choices and resources for their desires that satisfy different goals. As a result, it is critical for the manufacturer to put the finished product in the distribution network so that it is presented to the customer as affordable as possible. Previously, to solve this problem, companies used to provide multiple warehouses in different parts of the chain. However, the dynamic nature of today's marketplace turns it into an uneconomic alternative since high-risk moves such as customers' shopping habits are constantly changing, and competitors are eliminating existing products and offering new ones. Changing orders make the company always have warehouses full of outdated products. Furthermore, the high cost of storing the goods in the warehouse increases the final price of the product.
- Companies have found that maximizing the performance of a segment may not have much impact on the performance of the entire set. For example, if a purchase can be made at a lower price, the cost of producing the finished product may increase due to deficiencies in other manufacturing sectors. Therefore, it is necessary to consider the effect of that decision on the whole supply chain when deciding for a segment.

For these reasons, the use of a sustainable supply chain professional management system which incorporates the three groups of social, economic, and environmental factors is an indispensable choice for most companies. Managers of a firm within the sustainable supply chain benefit from the position of other related firms (Oh and Jeong, 2019). By exchanging the right market information, they utilize intra-organizational and extra-organizational knowledge and information and coordinate activities to keep the whole chain in competition. To synchronize the whole set, the sustainable supply chain manager must monitor the relationships between all the nodes within the chain. These communications, which help managers with information acquisition, can lead to a wealth of knowledge needed to design an optimal supply chain. This accumulated knowledge must be managed to analyze, evaluate, and provide appropriate outputs for use in chain design (Schoenherr et al., 2014).

Knowledge management is one of the interesting and challenging topics of management science in the new millennium. Its scope, application, and uses have expanded such that, as an interdisciplinary field, it is highly considered in the management literature (Halley and Beaulieu, 2005). KM is a new and valuable approach, along with other business and competitive strategies. In this context, sustainable supply chains need to think about implementing KM programs to take advantage of its potential benefits. Today, efficient managers must obtain the necessary data from multiple internal and external production systems, databases, and resources. To gain competitive advantage, managers must analyze and correlate raw data, process them into meaningful organizational information, and then convert that meaningful organizational information into useful knowledge (Dumitrache et al., 2009).

The ideal way for this purpose is to distribute and share this information. In doing so, a process must be initiated so that it can increase the value of chain knowledge assets. Ultimately, these managers need to be able to transform chain knowledge into business success and, by applying it, create competitive advantage, sustainable growth, and increased resources. To achieve sustainable competitive advantage, organizations and supply chains must pay attention to existing knowledge and how to use it effectively and create a structure for using new information and knowledge (Dwivedi and Butcher, 2009).

Thus, a dynamic system approach will be used herein to investigate this knowledge. The reason for using the dynamic system is its basis and results expected to be extracted from it. A dynamic system is a theory of system structure that consists of a set of tools for illustrating complex systems and analyzing the dynamic behavior of their information. A dynamic system approach is a policy-based approach that assesses the impact of changes on a system over time. The most important feature of this approach is to explain the internal structure of the system under the study in order to determine how the various factors of the system are interdependent and to examine how they change with different decision-making processes (Madani, 2010).

3.2. Identifying the Research Variables

The data required for this research were collected based on available data, documents available in the field, past research, and interviews with experts in this field. Table 1 tabulates the key variables used for modeling the research problem.

Table 1. Model parameters.

No.	Variables	Stability/Background Dimension	References
1	Market share	Economic	Oh and Jeong, 2019
2	Sale	Economic	Niu et al., 2019
3	Profitable	Economic	Badhotiya et al.,2019
4	Cost	Economic	Alinaghian and Zamani, 2019
5	Price of product	Economic	Liu et al., 2019
6	Material efficiency	Economic	Shafique et al., 2019
7	Market requirement for environmental products	Economic	Tseng et al., 2009
8	Transport cost	Economic	Wong et al., 2014
9	Cost of establishing a warehouse	Economic	Alayet et al., 2018
10	Manpower cost	Economic	Doolun et al., 2018
11	The allocation of environmental equipment	Economic	Liu et al., 2019
12	Investing in environmental field	Economic	Shafique et al., 2019
13	Raw material inventory	Economic	Tseng et al., 2009
14	Delivery time	Economic	Wong et al., 2014
15	Annual percentage of product return	Economic	Alayet et al., 2018
16	Pollution	Environmental	Shafique et al., 2019
17	Green product rate	Environmental	Tseng et al., 2009
18	Green mental imagination	Environmental	Alinaghian and Zamani, 2019
19	Greenhouse gases emission	Environmental	Niu et al., 2019
20	Waste rate	Environmental	Badhotiya et al., 2019
21	Waste inventory	Environmental	Alinaghian and Zamani, 2019
22	Environmental regulations	Environmental	Niu et al., 2019

No.	Variables	Stability/Background Dimension	References
23	Green image	Social	Badhotiya et al., 2019
24	Participation in community development	Social	Alinaghian and Zamani, 2019
25	Brand	Social	Niu et al., 2019
26	Social responsibility	Social	Shafique et al., 2019
27	Cooperation with customer	Social	Tseng et al., 2009
28	Business ethics	Social	Wong et al., 2014
29	Training of human resource	Social	Dwivedi and Butcher, 2009
30	Management support	Social	Rebs et al., 2019
31	Corruption and bribery ratio	Social	Hendalianpour et al., 2019
32	Customer satisfaction	Social	Nabavi et al., 2017
33	Knowledge development rate	Social/KM	Liu et al., 2019
34	Level of organization knowledge	Social/KM	Dwivedi and Butcher, 2009
35	Activity motivation	Social/KM	Rebs et al., 2019
36	Organizational knowledge discount rate	Social/KM	Koberg and Longoni, 2019
37	Discovering the strengths of organization knowledge	Social/KM	Koberg and Longoni, 2019
38	Sharing knowledge	Social/KM	Dwivedi and Butcher, 2009
39	Problem-solving techniques	Social/KM	Liu et al., 2019

3.3. Develop a Dynamic System Model

The criteria defined and evaluated using the experts' points given in Table 1 are introduced to the model. Figure 2 illustrates all the state variables, rates, and aids introduced in Table 1 and depicts the relationships between these criteria.

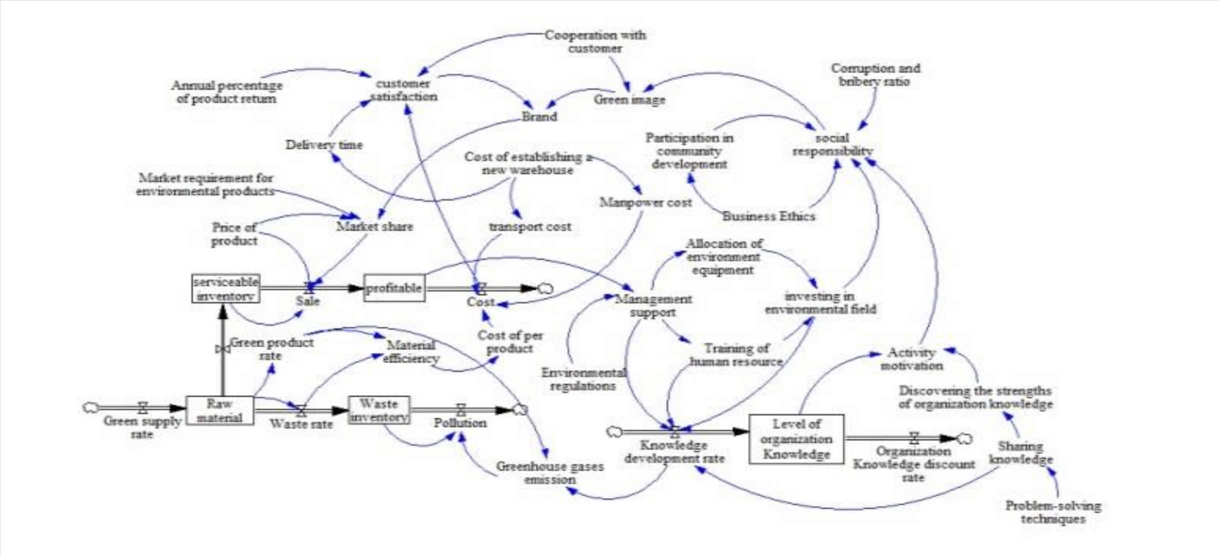

Figure 2: Research problem model developed in the current work.

3.4. Modeling Time Horizon

Based on the opinions of the experts and the literature on the subject, a 36-month time horizon, i.e. three years, was considered as the time sufficient for feedback performance.

Formulating dynamic hypothesis: The dynamic hypothesis is an explanation of the behavior of the reference state that must be consistent with the purpose of the model. A designer uses a dynamic hypothesis to extract and test the consequences of feedback loops. The graphs which illustrate the underlying mechanisms driving the system's dynamic behavior are then created. A model cannot be built without understanding feedback loops. Having a good dynamics hypothesis and a well-known underlying mechanism means that it provides enough information to start the system on the level and rate equations. Then, one can move on to the next stage of the modeling process, i.e. formulation (Pruyt, 2010). After talking to experts and reviewing previous research, it was found that some of the criteria are more effective. Due to similar effects, some were eliminated to simplify the model.

Determining the model boundary: Precisely assigning system and model constraints is of great importance in the modeling process. All the important members which affect other parts of the system and are significantly influenced by system members must be modeled as internal variables. However, all the components which seriously impact on the system, but are not sufficiently affected by the system, are external variables that are eliminated along with other components. In this case, the dynamic system helps to expand the boundaries of mental models. Table 1 lists the key variables used for modeling the research problem.

Research loops: The next step introduces the most important and effective loops in this model, which are "serviceable inventory" and "profitability" state variables (see Figure 3), "waste inventory" and "raw materials" state variables (see Figure 4), and loops related to "the level of organizational knowledge" state variable (Figure 5).

In the loops related to serviceable inventory and profitability state variables (Figure 3), the variable serviceable inventory is fed from green production rate variable. As can be seen, naturally, at a higher rate, the serviceable inventory increases more with a rise in the production. Since there is a product available for sale at the time of sale, the sales increase. In the next section, auxiliary variables affecting rate variables and other auxiliary variables which indirectly influence rate variables are examined.

As can be seen, we first deal with the variables related to sales. Market share and product prices directly affect sales and work quite clearly; a greater market share and volume of the products of the respective company, compared to the competitors' product in the market, leads to more likely sales. In addition, the lower the price of the product is, the higher the volume of demand for the product becomes, so sales boost. Furthermore, because of changes in customer demand, this price also affects market share. Other variables influencing market share include market demand for environmentally friendly products and product branding. With an increase in the market demand for eco-friendly products, if the market share of the competitor firms is constant, its market share rises. Furthermore, the stronger the brand is, the greater the demand for the product becomes, which increases the market share.

The same rules apply to the profitability state variable. Generally, an increase in the sale level results in a subsequent rise in the profits and reduces costs; the higher the costs decrease, the more the profits increase. Profitability itself has an impact on management support; as profits rise, the management increases its support for the organization by making a positive outlook on the correct direction of the company to move upward.

There are also cases which affect the cost rate variable. The creation of new warehouses entails costs, such as the cost of establishment and the manpower employed in these warehouses, which increase the cost rate. However, by creating these warehouses and reducing the routes by which the products are delivered to customers, shipping costs decline, which ultimately drops the cost rate.

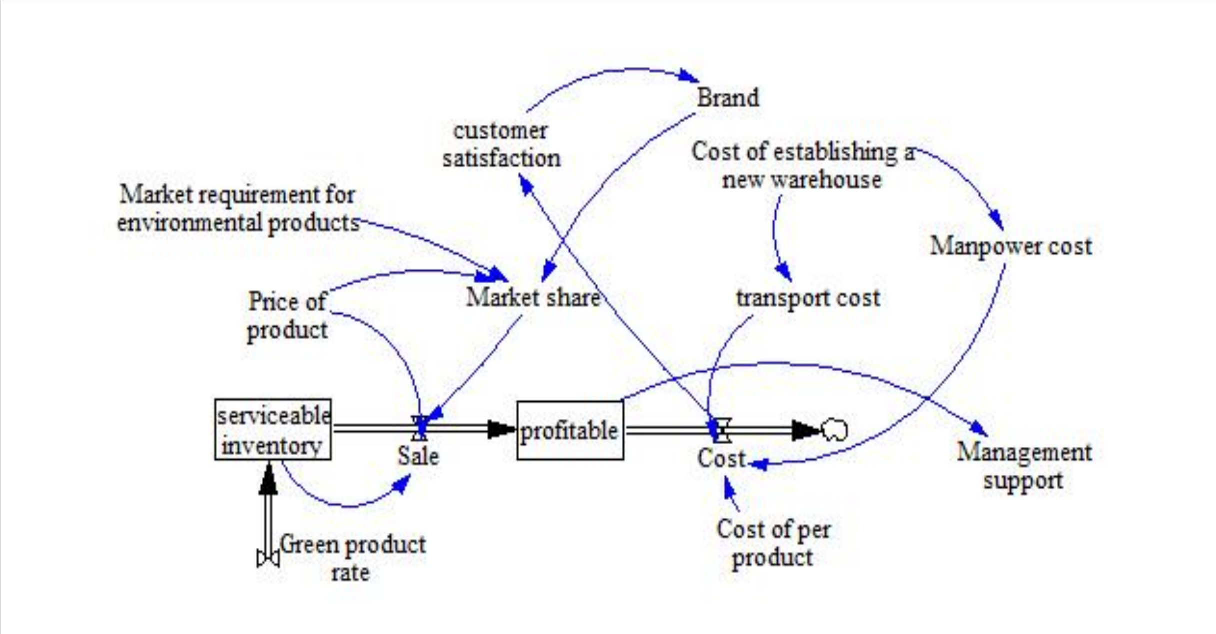

Figure 3. Loops related to serviceable inventory and profitability state variables.

From the loops for the state variables of waste inventory and raw materials (Figure 4), it is observed that the supply rate of green materials affects the state variable of raw materials. With an increase in this supply rate, the amount of raw material available increases and raw material can easily be supplied. Moreover, with an increase in green raw materials, the production rate of green products rises if production capacity is available. Moreover, as the waste rate increases, the raw material converted to the product decreases. Further, an increase in the waste rate leads to a subsequent rise in the waste inventory, which consequently raises the level of pollution due to the lack of conversion of waste material to green products.

Increasing the production rate of green products reduces the amount of greenhouse gas emission from incomplete combustion of petroleum products, thereby decreasing pollution. Meanwhile, the effectiveness of materials rises with an increase in the production rate of green products and the reduction in the waste rate. Therefore, the greater the number of green products produced, the closer the goal of production is, and thus the greater the effectiveness becomes. In addition, a lower amount of waste raises the production rate and the effectiveness.

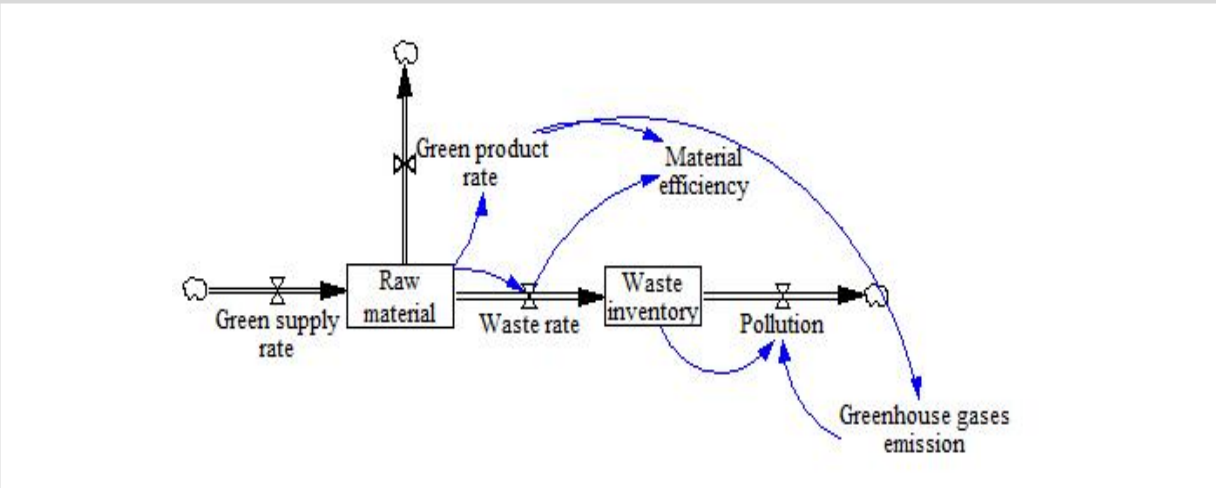

Figure 4. Loops related to waste inventory and raw materials state variables.

Figure 5 presents the loops corresponding to the state variable of the level of organizational knowledge. The rate of knowledge development, as a variable affecting the level of organizational knowledge, is itself influenced by environmental investment variables, human resources training, and management support. Thus, the higher the rate of knowledge development, the more the organization is affected by this rate, and the higher its knowledge for survival in the industry is. Since a part of the investment is in environmental education, and the other is related to its mechanisms, a greater investment in the environment needs more the training to be implemented. Thus, with an increase in this parameter, the rate of knowledge development also rises. Human resources training also directly affects this rate. Furthermore, greater management supports cause the organization to better respond to the support, which leads to more training and a further increase in the level of development.

Developing problem-solving skills such as brainstorming help different people share organizational knowledge, which increases the rate of knowledge development because of the integration of the knowledge of the staff of the organization. This knowledge sharing and knowledge level of employees reveal hidden strengths in organizational knowledge. Additionally, this discovery and appreciation, along with the level of organizational knowledge, motivate individuals in the organization. As these incentives are increased and people find their way into the organization, the organization works together its people to achieve its goals. Also, because organizations like this have products which can have a profound impact on society's health, they are committed to it. Therefore, the organization has high social responsibility which will be affected by other variables such as business ethics, bribery and corruption, and participation in community development.

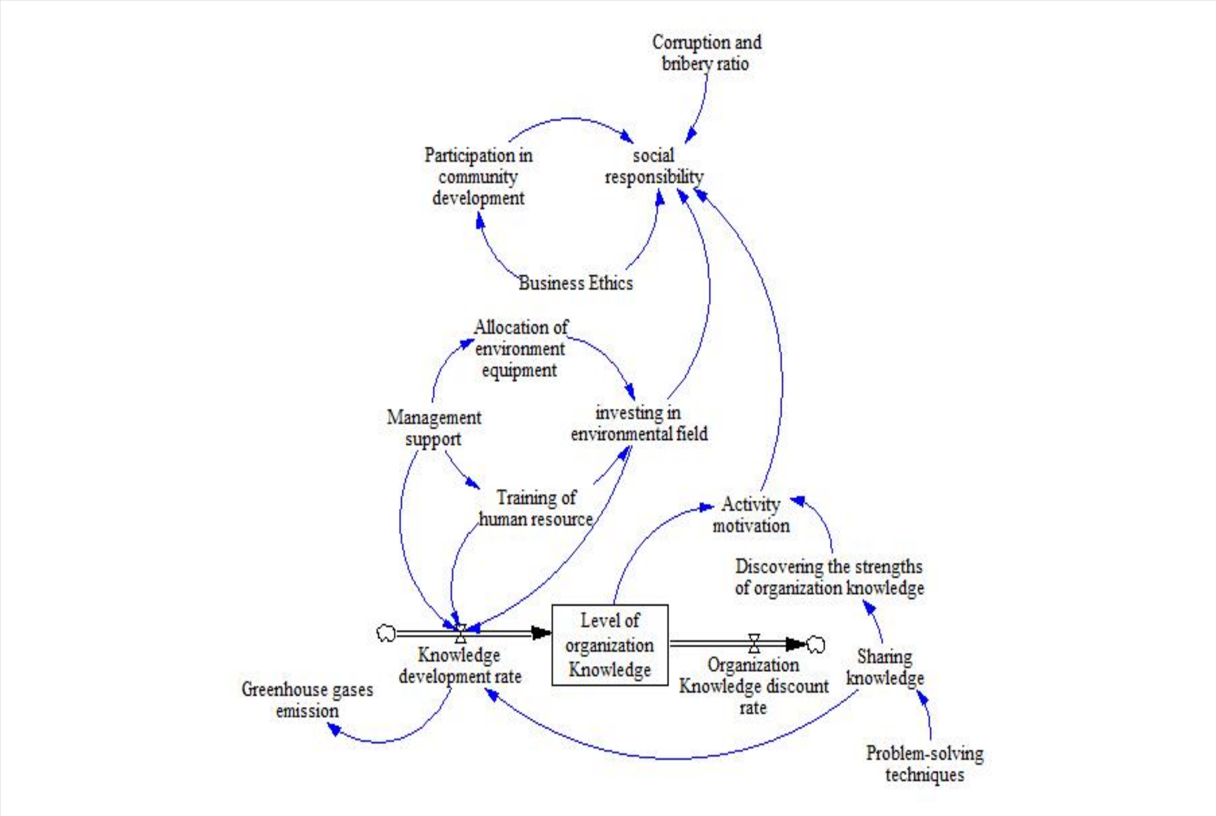

Figure 5. Loops related to "level of organizational knowledge" and "community affairs" state variables.

3.5. Dynamic System Model Implementation and Validation

Sterman (2002) presents a set of tests for model validation which were used herein to evaluate the validity of the proposed model.

a. Boundary Adequacy Test

Since all the important factors in the model have been studied and proved by other experts in previous studies, to investigate the effectiveness of these factors, we evaluate their impact on the overall model by eliminating each one. Figure 6 displays the effect of eliminating "product price" factor, which affects the sales. In fact, eliminating this variable means ignoring it in the simulation, but not the absence of this variable in the real world. It is also observed that these variables are strongly influenced by each other. Figure 7 shows the effect of eliminating "green production rate" factor on the serviceable inventory variable. Ignoring this factor also results in a significant reduction in serviceable inventory. Figure 8 illustrates that the effect of eliminating "environmental investment" factor on the level of reduction in organizational knowledge.

Figure 6. Impact of eliminating product price factor on sales.

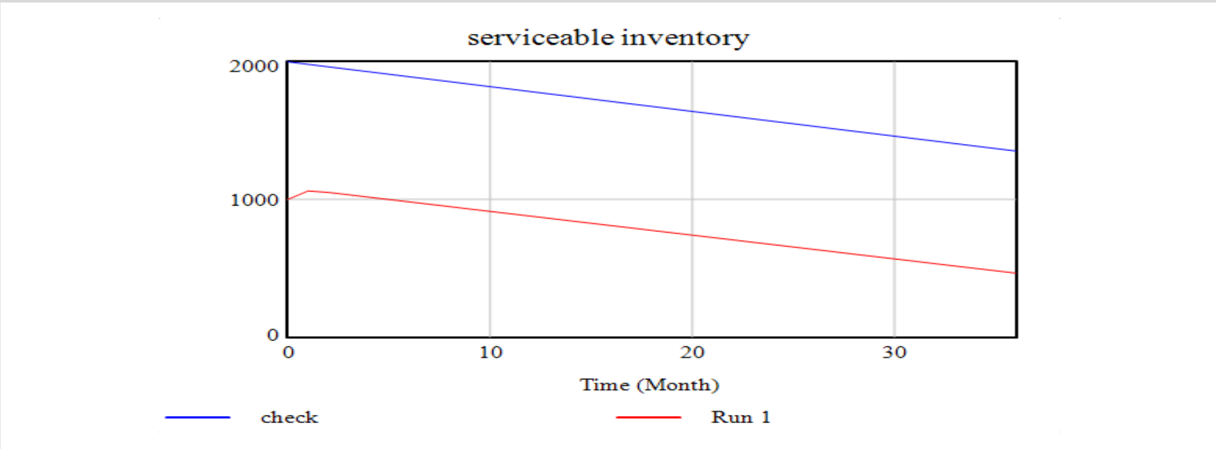

Figure 7. Impact of eliminating green production rate factor on the serviceable inventory variable.

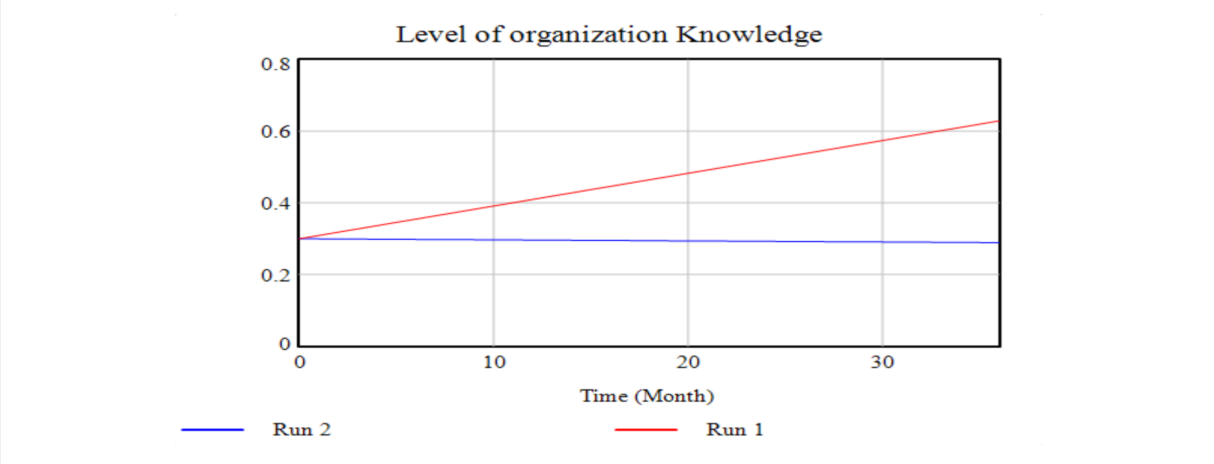

Figure 8. Impact of eliminating environmental investment factor on the level of organizational knowledge.

b. Structure Evaluation Test

Structure validation means that the relationships used in the model have effectively incorporated the actual relationships associated with the research purpose. Since the model equations developed are written in Vensim software environment, the software verified the accuracy of the structure of the model equations

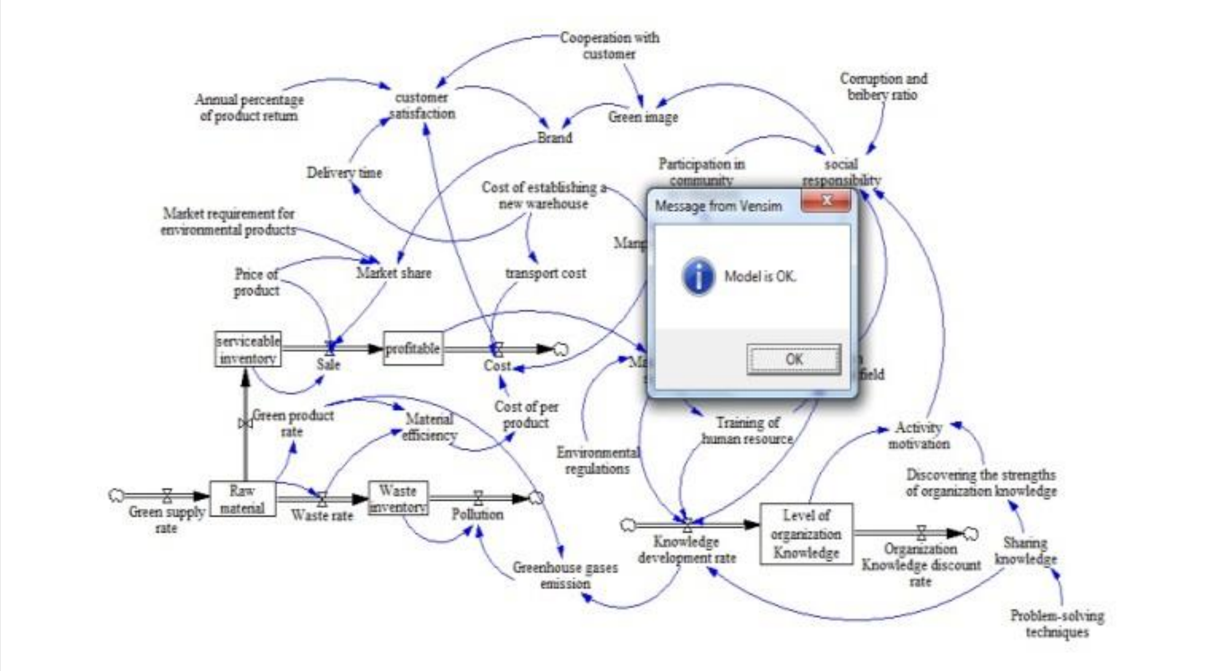

Figure 9. The equation structure validation by Vensim software.

c. Parameter Evaluation Test

To evaluate the model parameters and factors, they were compared with the reference model. Finally, these cases were confirmed by the expert advice.

d. Extreme Conditions Test

In this test, we investigated the model behavior under conditions where the model inputs are in extreme conditions, i.e. at their minimum or maximum states. Moreover, the stability of the model under these conditions was verified. In the boundary adequacy test, the status of the variables was examined in the infinite state (the maximum value).

Condition 1: Increasing the green supply rate to 1, i.e. the supply of all green materials (see Figure 10).

If the supply of green materials increases too much, the volume of waste is reduced, which is one of the most important goals of the current research. However, the bottom line is still to supply the material in a completely green way. In this case, the amount of waste reaches zero. Indeed, we are always looking for zero waste, but this can be associated with irrational cost increases. Therefore, reaching zero waste cannot be considered as a necessarily desirable condition.

Condition 2: The green production rate is at its highest level (Figure 11).

As can be seen in Figure 11, if the green production rate of the oil industry rises, the serviceable inventory will jump greatly

Condition 3: The best rate of knowledge development is assumed (Figure 12).

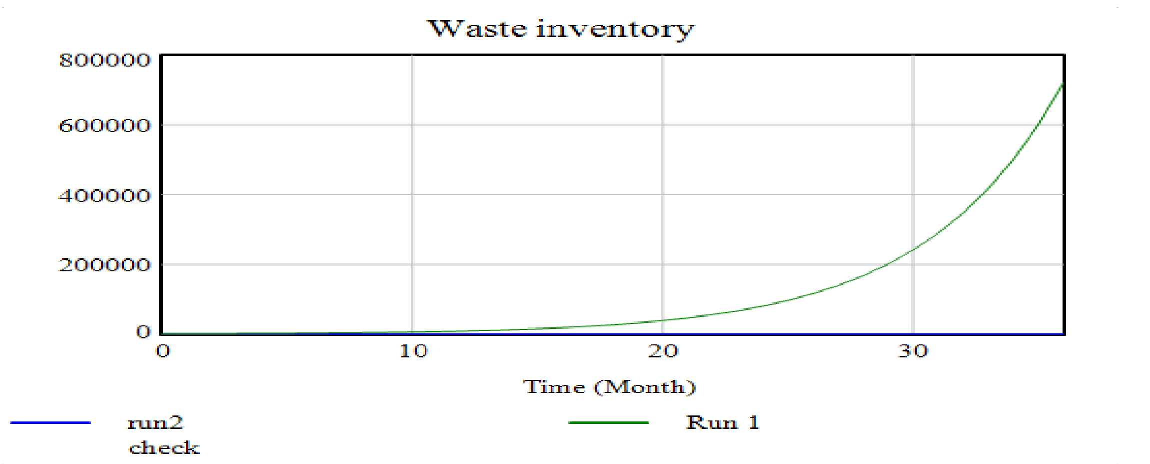

Figure 10. Model behavior in the case of supplying all green materials.

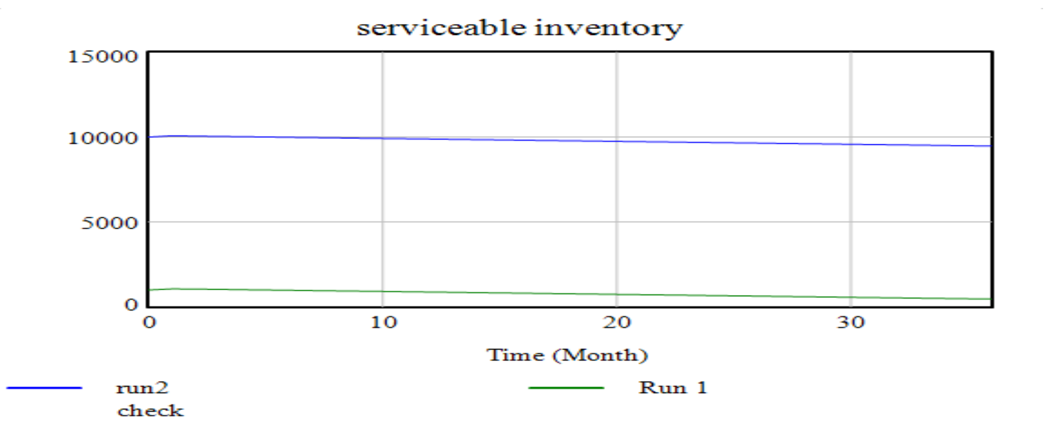

Figure 11. Model behavior in extreme green production rate scenarios.

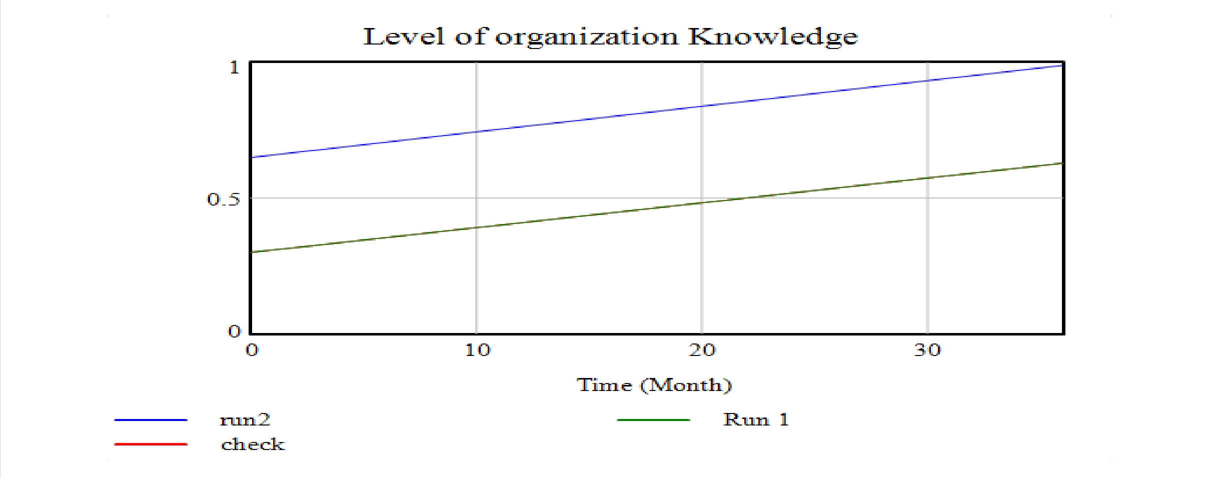

Figure 12. Model behavior at the extreme knowledge development rate.

Based on Figure 12, if the rate of knowledge development reaches its peak, it impacts on the success of the organization increases, and thus the level of organizational knowledge rises as a result of the desire in the organization to move toward knowledge acquisition.

e. Integration Error Test

This test indicates the sensitivity of the model results to the selection of the time interval. To perform this test, the time frame of the model was changed from 36 months to 60 months. As delineated in Figure 13, no change was observed in the model behavior with increasing the model interval. If controlled, the effective factors still improve the performance.

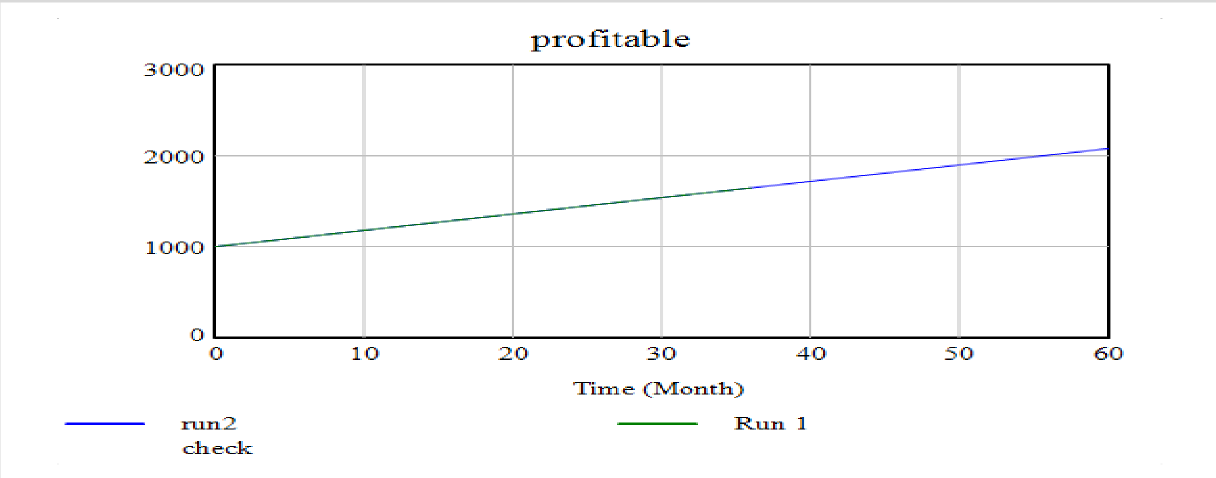

Figure 13. Model outputs at 36- and 60-months intervals.

f. Behavior Reproduction Test

The question of whether this model represents and reproduces system behavior in real terms is answered using a behavior reproduction test. Based on extensive reviews of previous studies, since the author believes that this research includes variables affecting the integration of knowledge and sustainable supply chains, system behavior can be predicted after identifying the criteria. Figures 14–17 reveal that by controlling and increasing organizational knowledge, waste can be reduced while profitability and social responsibility can be increased. However, performance improvement can be involved with many factors the coordination of which requires more time.

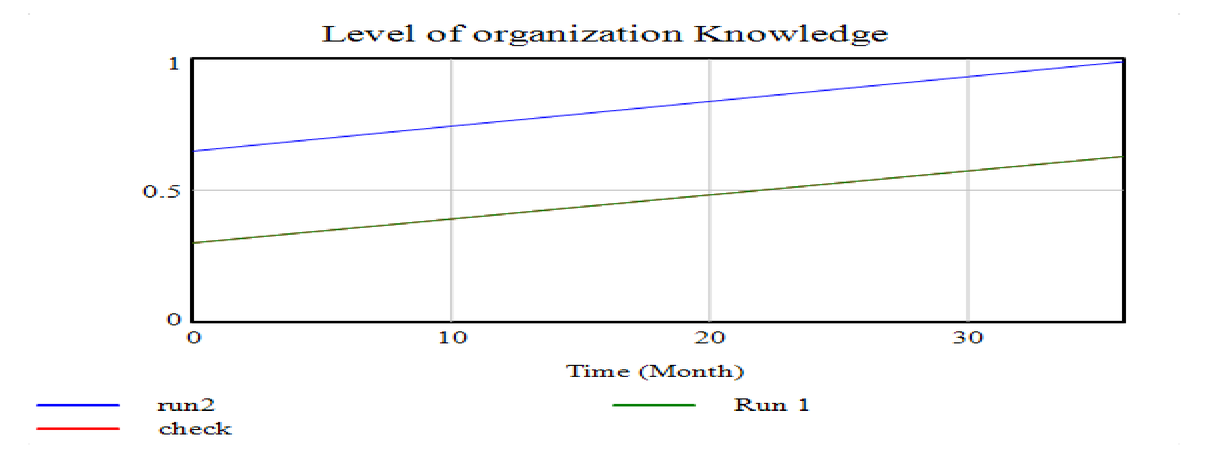

Figure 14. Increasing the level of organizational knowledge.

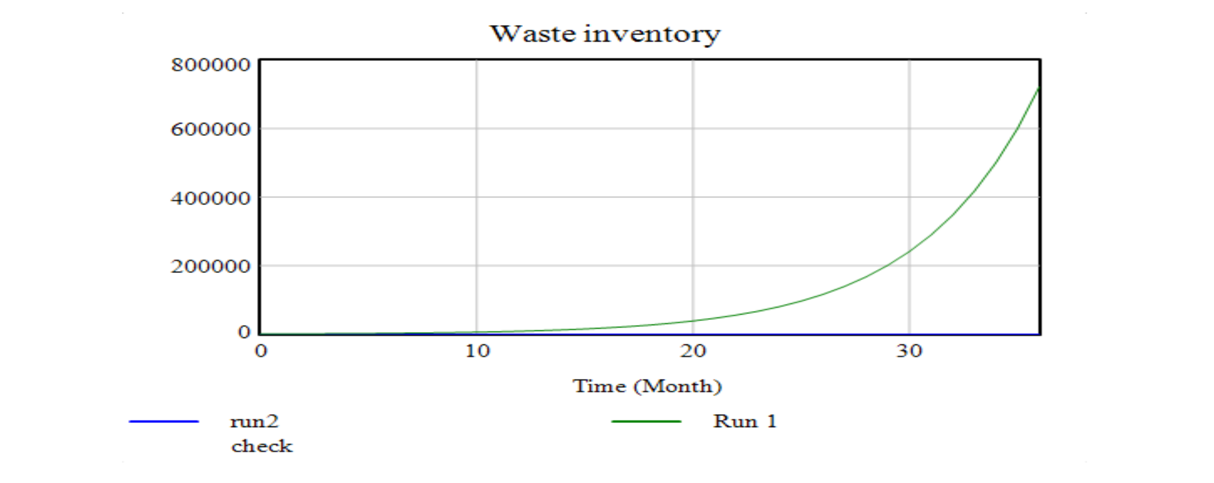

Figure 15. Waste reduction.

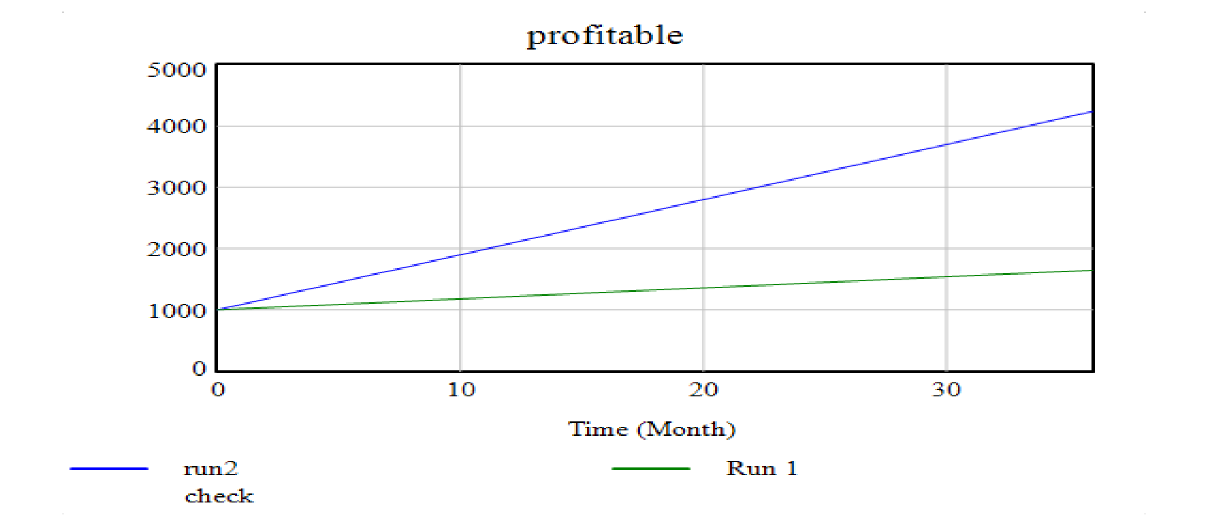

Figure 16. Increased profitability.

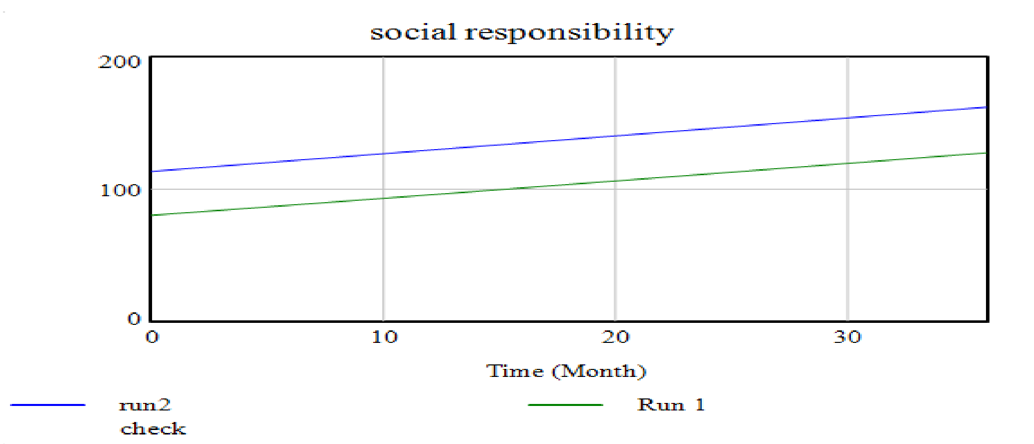

Figure 17. Increased social responsibility.

g. Sensitivity Analysis Test

In the next step, after simulating the system and examining the behavior of each variable, it is necessary to examine the variation in the variables and their associated behavior. This sensitivity analysis was conducted by regarding the variations in parameters in the previous sections and the diagrams related to these variations.

3.6. Analyzing the Results and Presenting the Scenario

In the final step, after analyzing the model factors and determining the extent and type of impact on the targeted factors and variables of the research, an attempt was made to pave the way for achieving applied strategies by defining different scenarios and determining different values of influential index groups. According to experts and some official papers, different values are determined for fixed variables in both controllable and uncontrollable contexts for the organization. These values are achieved under different conditions of the organization and the environment. By setting different values for these influential indicators, five scenarios are considered (Table 2) as presented in Figure 18.

Considering the variables that the system is now able to modify, the variables that the system does not decide on and are applied by the external environment, and the combination of variables, which is declared by decision-makers to be applicable, five scenarios are developed. Table 2 tabulates the values written for each scenario and lists the rate of decrease or increase (depending on the nature of the variable) in the variables.

Table 2: Research scenarios.

Variables	The percentage of increase in the variables of various scenarios				
	1	2	3	4	5
Product price	14	9	17	9	18
Green supply rate	25	16	11	25	16
Problem-solving techniques	20	22	11	17	23
Environmental laws	23	9	20	16	20
Warehouse construction cost	12	13	10	14	19
Annual return percentage	10	13	11	14	15
Corruption and bribery rate	8	12	9	15	10
Business ethics	13	11	18	10	20

Variables	The percentage of increase in the variables of various scenarios				
	1	2	3	4	5
Customer collaboration	20	15	20	23	17
Market demand for environmental (green) products	19	15	25	20	15

In scenario 1, the value of the product price index is increased by 14%, which will likely affect market share and sales. In addition, the green supply rate is increased by 25%, which can also influence the amount of raw material used. Problem-solving techniques have been increased by 20%, which has a positive impact on the organizational staff's share of organizational knowledge and, ultimately, on the level of organizational knowledge after changing the rate of knowledge development. In addition, the environmental law index is raised by 23% to evaluate its impact on the level of management support. Furthermore, a 12% increase in the cost of construction of a warehouse reduces the distance to delivery places because of new warehousing, thereby dropping shipping costs and delivery time. Also, return products are reduced by 10% annually, and corruption and bribery rate are decreased by 8%. Business ethics are increased by 13%, customer engagement by 20%, and market demand for environmental products (green) by 19%.

- In scenario 2, the product price index, the green supply rate, problem-solving techniques, the environmental law index, and the warehouse construction cost index increase by 9, 16, 22, 9, and 13% respectively. The annual percentage of return products and the rate of corruption and bribery both decline by 12%. Business ethics, customer engagement, and market demand for environmental products (green products) are increased by 11, 15, and 15% respectively.
- In scenario 3, the product price index, the green supply rate, problem-solving techniques, environmental laws, and the warehouse construction cost index are increased by 17, 11, 11, 20, and 10% respectively. The annual percentage of returned products and corruption and bribery rate drop by 11 and 9% respectively. Business ethics, customer engagement, and market demand for environmental products all increase by 18, 20, and 25% respectively.
- In scenario 4, the product price index, the green supply rate, problem-solving techniques, environmental laws, and warehouse construction cost index increase by 9, 25, 17, 16, and 14% respectively. The annual percentage of returning products and the corruption and bribery rate decline by 14 and 15% respectively. Business ethics, customer engagement, and market demand for environmental products increase by 10, 23, and 20% respectively.
- In scenario 5, the product price index, green supply rate, problem-solving techniques, environmental laws, and the cost of building a warehouse increase by 18, 16, 23, 20, and 19% respectively. The annual percentage of returning products and the corruption and bribery rate decrease by 15 and 10% respectively. Business ethics, customer engagement, and market demand for environmental products rise by 20, 17, and 15% respectively.

Given these scenarios, the model is run again. Then, the variations in the state variables in these five scenarios in terms of the changes in the studied variables (Table 2) are plotted for the state variable of profitability in Figure 18.

Figure 18 delineates the simulation results of the five scenarios. In scenario 1, the value of the product price index increases by 14%, green supply rate by 25%, problem solving techniques by 20%, environmental laws by 23%, warehouse construction cost by 12%, business ethics by 13%, customer engagement by 20%, and market demand for environmental (green) products by 19%. In addition, in this scenario, the annual percentage of returned products decreases by 10%, and the corruption and bribery rate declines by 8%, showing the best performance for the profitability state variable. Because of the large scale of profitability, scenarios 5 and 2 roughly overlap.

Given the different market conditions such as a tendency to reduce CO_2 and environmental pollutants; the social status; and the different economic conditions such as recession, boom, and moderation; demographic conditions; and demand, the obtained figures were examined through evaluating various studies in this field and receiving expert advice.

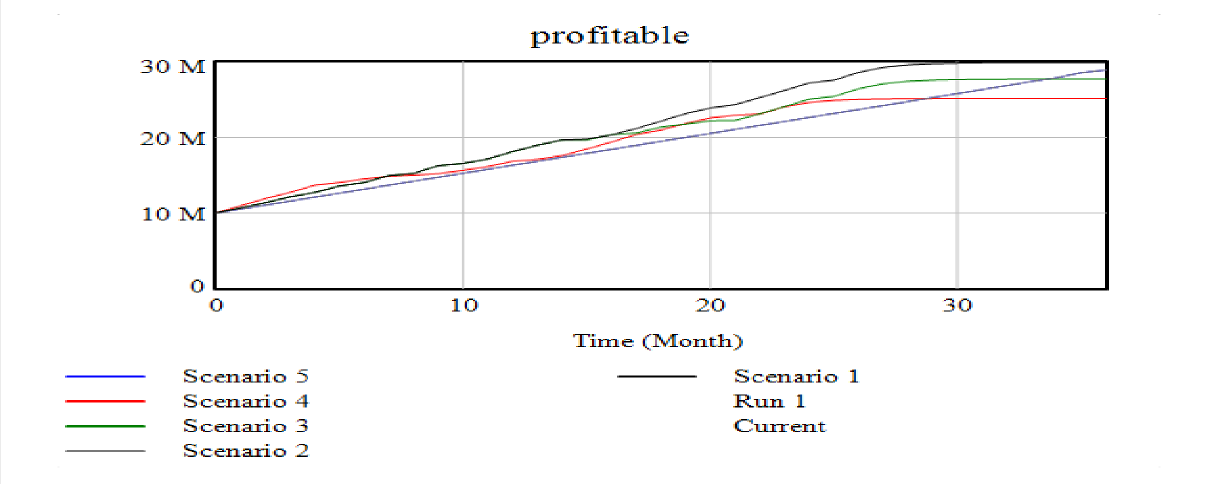

Figure 18. Different scenarios in profitability state variable.

4. Conclusions

To survive and succeed in today's markets, building a supply chain and striving to maximize the benefits of the whole supply chain is of great necessity. By forming a network of organizations and operating within a supply chain, manufacturers, suppliers, distributors, warehouses, retailers, and customers have sought to compete in the expanding global markets. As a result, organizations work together toward common goals. In this context, supply chains have been the subject of intense interest among the researchers. As environmental, social, and financial problems began to develop, a sustainable supply chain emerged and was increasingly used. Given the importance of this issue, the current work also addresses this issue. In previous researches, various methods have been used to investigate the sustainable supply chain and its influencing factors such as the SD method, artificial neural networks, and statistical and descriptive methods. Considering all the aspects affecting the system and the sustainable supply chain and regarding the time variations and the interactions between the effective factors, the SD method offers a robust simulation of the system and its modifications. However, this method does not provide a solution for optimizing user-configurable values. Hence, the present research uses the SD method, adds knowledge management variables, and incorporates them into the SD model to determine optimal values of variables and obtain final values for decision variables. To do so, variables and relationships between them are first identified by reviewing prior studies and expert opinions, and the model is then designed. Finally, five scenarios were defined, and it was demonstrated that the optimal values for 10 main variables which have the most impact on the variables of profitability, organizational knowledge level, and waste rate are the same as those in scenario 1.

Therefore, considering the results of the present work, approaching the first scenario, modifying their work methods and methodologies, defining a working strategy to achieve these goals, and identifying ways to counteract the factors that this study considers as external parameters non-regulated by the organization, oil companies can achieve their target of enhancing the company's profitability.

This study provides a basis for applying knowledge management as a guide tool to other areas such as retail and manufacturing. For future studies, given the gaps expressed in this study, other new techniques such as business intelligence and data mining can be employed for analysis purposes but at a small operational level. Taking the power of these techniques into account, critical issues can be identified in the first stage through literature review, annual reports, and case study analyses. Moreover, this can be achieved through personal interviews with top-level management and then with intermediate-alevel and operational-level management of oil industry subsidiaries.

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