E-ISSN: 2717-2937 | P-ISSN: 2783-1337

International Journal of Research in Industrial Engineering

www.riejournal.com

Int. J. Res. Ind. Eng. Vol. 12, No. 1 (2023) 73–87.

Paper Type: Research Paper

Designing a Hybrid Model for the Green Supply Chain in Guilan Steel Industry

Sirous Balaei[1], Nabiollah Mohammadi[1,*], Homa Doroudi[1]

[1] Department of Management, Zanjan Branch, Islamic Azad University, Zanjan, Iran; sirousbalaei@yahoo.com; mohammadi13928@gmail.com; homa_doroudi@yahoo.com.

Citation:

Balaei, S., Mohammadi, N., & Doroudi, H. (2023). Designing a hybrid model for the green supply chain in Guilan steel industry. *International journal of research in industrial engineering, 12*(1), 73-87.

Received: 17/08/2022 Reviewed: 20/09/2022 Revised: 11/10/2022 Accepted: 01/12/2022

Abstract

Due to the importance of environmental effects of manufacturing system in recent decades, the production systems are obliged to comply different environmental regulations. The present research, aims to design a green supply chain model for Guilan Steel industry with a hybrid approach. This study is applied research in term of purpose, exploratory in term of method, quantitative and qualitative in terms of data type. A researcher made questionnaire are applied, in addition to interview, for data gathering. The under-study research population includes steel industry experts out of them, 12 experts were selected for data gathering phase. Conducting the research, first applying fuzzy Delphi method, 5 main factors and 25 important sub-factors were identified. Then, using fuzzy DEMATEL and Interpretive Structural Modeling (ISM) methods, the importance of each facto was determined, in which two factors "external environment study" and "internal environment study" were at the highest level of the importance, while "waste reduction", "waste recycling" and "purchasing based on environmental products" were at the last level. These variables are interrelated and affect their next levels.

Keywords: Green supply chain, Delphi method, Fuzzy DEMATEL, ISM.

1 | Introduction

Supply chain of the organizations can be simply defined as a set of directly involved entities in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer [1]. Today, competition along or across chains is of particular importance among researchers. The supply of products and services by changing the pattern of customer competition has led to a change in the type of market competition from the state of competition between independent companies to competition between supply chains. Supply chain design has extensive literature, most of which is related to the single supply chain, and the existence of competing supply chains and their emergence in the future have not been considered. However, supply chains compete with each other for greater market share. Therefore, supply chains must be prepared for future competitiveness even if there is no competitor at the same time [2].

Corresponding Author: sirousbalaei@yahoo.com

https://doi.org/10.22105/riej.2022.298634.1327

In recent years, the advent of new technologies and shifts in global markets have necessitated the Supply Chain Management (SCM), so that different organizations use SCM inevitably to create and maintain their competitive position [3]. SCM involves the planning of the entire supply chain from the raw material supplier to the end customer. Since SCM has become the core of the organization's management in the 21st century, there is a high interest to exploit the full potential of SCM in increasing organizational competitiveness [4]. SCM is considered as a business strategy. It has evolved over time from a focus on optimizing the internal processes of an organization [1].

Green Manufacturing (GM) is introduced as a manufacturing process that utilizes input data with relatively low environmental impacts, whereas is highly efficient and creates little waste or pollution, and Greenhouse Gas Emission (GHG) [5]. Today's world experiences an increase in pollution, environmental problems and countries' concerns about the earth climate. Climate change is quite obvious at present, and its impact is falling adversely on the population and the world economy [6]. It caused to increase in environmental concerns from consumers, manufacturing companies, governments and communities around the world. On the other hand, global organizations attemp to cerate competitive advantage by improving their environmental performance according to the environmental laws and standards and increasing customers' knowledge about green products and services. Therefore, the necessity of green supply chains has obliged governments to set environmental standards and on the other hand the demand of customers for the supply of green products [7]. It has been more than two decades since green SCM has been studied. Many companies and industries are keen to initiate a partnership with the suppliers, so they would be able to enhance their competitiveness performance globally [8].

The functions of green supply chain are summarized in three important themes: green design (product), green production (process), and product recycling. In fact, the green supply chain is based on the integration of internal and external measures to control environmental effects on the product life cycle by sharing information, coordination and cooperation of the all players in supply chain [9]. Green SCM integrates SCM with environmental requirements at all stages. Internal and external actions in the supply chain include product design, selection and supply of raw materials, production and manufacturing, distribution and transfer processes, delivery to the customer and, recycling in order to maximize energy efficiency. Since the issue of the environment was linked to the economy and countries have come to the conclusion that environmental protection can increase productivity, different approaches have been taken to realize these technologies, one of which is the latest, the green SCM [10]. The idea of green SCM is to eliminate or minimize waste, which as an important innovation helps the organization to develop strategies to achieve common profit and market goals by reducing environmental risks and enhancing environmental efficiency [11]. Homayounfar et al. [12] proposed a hybrid fuzzy MCDM approach based on fuzzy Delphi, fuzzy analytical hierarchy process and fuzzy VIKOR techniques to evaluate and select the green suppliers of Saipa Corporation. The results indicate that the proposed approach is an effective framework for prioritizing green suppliers of Saipa Corporation. Examining the theoretical issues of the research shows that companies are increasingly believing that considering green SCM measures and observing them as a key strategy could lead to great impact on organizational performance. Rezaee Kelidbari et al. [13] used a combined multiple criteria decision-making method (extent analysis and PROMETHEE) for supplier selection in a spare producer company in Iran. The result of this belief can be seen in the implementation of ISO 14001 standard by most companies. For example, Laari et al. [14] stated that paying attention to green management activities will improve the performance of the organizations in financial and environmental dimensions. Therefore, identifying green SCM measures can be very important. Some researchers believe that waste reduction, total quality management, ISO standards and reverse logistics, which are measures of green SCM, have a significant effect on green productivity. Thus, it can be said that in today's era, various organizations and industries by identifying and observing green SCM measures such as waste reduction, total quality management, green production, green design, reverse logistics, etc. can easily achieve the goals with more efficiency [15]. However, the industrial development trend shows that, the green issues are neglected by many

Balaei et al.| Int. J. Res. Ind. Eng. 12(1) (2023) 73-87

industries especially in developing countries. So, this study aims to present a hybrid model to investigate the green supply chain in Guilan Steel industry as one of the leading industries in Iran.

2 | Methodology

This research is descriptive-survey in terms of method and practical in terms of purpose. In term of time horizon, it is cross-sectional research and from the methodological point of view, this research is based on mix methodology. The experts include academic experts in supply chain and top managers of Guilan Steel company who are familiar with SCM which have the following conditions: 1) at least 10 years of work experience, 2) at least 5 years of work experience in managerial positions, 3) having a master's degree or higher in the fields of industrial management or industrial engineering. According to the mentioned features, 5 academic experts and 7 industry experts were identified as research experts to conduct the research, based on the literature review and studying the scientific papers related to the green supply chain, its criteria were extracted. In this research, first a Delphi questionnaire was designed based on the factors identified from the literature review and was sent to the experts in 3 rounds. Analyzing the answers using, 25 more important factors of green supply chain with the score of ≥ 0.7 were selected. Finally, in order to investigate the relationships between the main factors, other questionnaires were designed and sent to the research experts. According to the answers and applying Interpretive Structural Modeling (ISM) and DEMATEL methods these factors were structured and the critical ones were identified. The software used to implement the data analysis was, MATLAB software. In the following, methods used for data analysis are described.

2.1 | Fuzzy Delphi

Fuzzy Delphi method introduced by Ishikawa et al. [16] is a method derived from the traditional Delphi method and fuzzy set theory. According to Noorderhaben's study, fuzzy Delphi method solves the ambiguities in experts' opinions to a large extent [12]. In the first step of the research, fuzzy Delphi method is used to screen the factors identified in theoretical bases. In the next step, a questionnaire containing factors will be sent to the experts to determine the importance of each factor based on linguistic values (*Table 2*). After collecting the questionnaires, the results of the first round were sent to the experts in the form of a questionnaire so that they modify their judgments after reviewing the results of the initial stage, if it is needed. After collecting and analyzing the experts' judgments in the second round, the average difference was checked, if this difference is less than 0.2, consensus is achieved and the fuzzy Delphi steps will be completed. Otherwise, the analysis of the results of this round will also be sent to the experts, again. This process will continue until the experts achieve to the consensus in the judgments. If the experts decide to add a criterion during these rounds, this criterion will be added to the questionnaire in the next round and opinions about this criterion will be asked. At the end, in order to confirm the final criteria, the average score of each criterion should be compared with the threshold value (0.7). For this purpose, first the triangular fuzzy numbers of experts' judgments should be calculated and then their fuzzy average should be calculated to compute the average of n respondents' judgments. In this study, *Table 1* illustrates the utilized scale for transforming linguistic words into triangular fuzzy numbers.

Table 1. Verbal words and their fuzzy values.

Fuzzy Value	Linguistic Value
(7, 9, 9)	Very high
(5, 7, 9)	High
(3, 5, 7)	Medium
(1, 3, 5)	Low
(1, 1, 3)	Very low

Balaei et al.| Int. J. Res. Ind. Eng. 12(1) (2023) 73-87

2.2 | DEMATEL Method

DEMATEL is a graph theory-based technique, was first put forward by American scientist in Science and Human Affairs Program (SHAP) between 1972 and 1976 to resolve the complicated and intertwined problem group [17]. This structural modeling approach adopts the form of a directed graph, a causal-effect diagram, to present the interdependence relationships and the values of influential effect between factors. Through analysis of visual relationship of levels among system factors, all elements are divided into causal group and effected group and this can help researchers better understand the structural relationship between system elements, and find ways to solve complicate system problems [18]. At first, DEMATEL method focused primarily on the fragmented and even contradictory phenomenon to find a reasonable solution. With further research, this method has been widely applied in more and more areas. Currently, DEMATEL method has been applied to many fields. Moreover, DEMATEL method is currently applied in many other areas. The steps of DEMATEL method based on Sharifi and Homayounfar [19] are as follows:

1. Find out the factors influencing the under-examination system. A large number of literature reviews is required to search and collect relevant information in this phase.
2. Generate the initial direct-relation matrix form a committee of experts, and acquire the assessments about direct affect between each pair of elements. Converting the linguistic assessments into crisp values, we obtain the direct-relation matrix A = [aij], where A is a n×n non-negative matrix, aij indicates the direct impact of factor i on factor j. When i = j the diagonal elements are zero (aij = 0).
3. Normalize the initial direct-relation matrix (D) through *Eq. (1)*. All elements in matrix D are complying with $0 \leq d_{ij} \leq 1$, and all principal diagonal elements are equal to 0.

$$D = \frac{1}{\max \sum_{j=1}^{n} a_{ij}} \ . \ A. \tag{1}$$

4. Acquire the total-relation matrix T using the *Eq. (2)* in which I is a n×n identical matrix. The element tij indicates the indirect effects that factor i have on factor j, so the matrix T can reflect the total relationship between each pair of system factors.

$$T = D\,(I - D)^{-1}. \tag{2}$$

5. Calculate the sum of rows and columns in matrix T through *Eqs. (3)* and *(4)*. The sum of row i (ri) represents all direct and indirect influence given by factor i to all other factors, and so ri can be called the degree of influential impact. Similarly, the sum of column j (cj) can be called as the degree of influenced impact, since cj summarizes both direct and indirect impacts received by factor j from all other factors.

$$r_i = \sum_{j=1}^{n} t_{ij}. \tag{3}$$

$$c_j = \sum_{i=1}^{n} t_{ij}. \tag{4}$$

Naturally, when i = j, the indicator ri + ci can represent all effects received by factor i. On the contrary, ri - ci shows the net effect that factor i has on the whole system. Specifically, if the value of ri - ci is positive, the factor i is a net cause, exposing net causal effect on the system. When ri - ci is negative, the factor is a net result clustered into effect group.

6. Construct cause-effect relationship diagram based on ri + cj and ri - cj. A cause-effect diagram can be drawn by mapping the dataset of (ri + cj, ri - cj).

2.3 | ISM Method

ISM is a method by which the effect of each element of the system on other varelements can be structured and analyzed. This approach, provide a comprehensive attitude to the system and details its performance [20]. In addition to ordering and directing the relations among the items of a system, the method helps to analyze and evaluate the effect of an element on other elements. Thereby, the relational complexity among the items is coped with, and the elements are ultimately classified on the basis of their drivingdependence power. The various steps of ISM method as follow:

Step 1. List the elements of the system.

Step 2. Establish the relationships among the elements in form of the Structural Self-Interaction Matrix (SSIM).

Step 3. Developed the reachability matrix based on the SSIM, and the matrix is checked for transitivity. The transitivity indicates that, if variable A is related to B and B is related to C, then A is necessarily related to C.

Step 4. Structure the elements of the reachability matrix into different levels.

Step 5. Depict a hierarchial graph based on the relationships in the reachability matrix.

Step 6. Review the ISM model developed in Step 5 to check against conceptual inconsistencies, and necessary modifications are made.

3 | Results

Since, the green SCM factors derived from the literature are to many, it is rational that a screening method be applied to filter the important factors. Therfore, a questionnaire consisting 35 items was designed for evaluating based on a five-point scale from unimportant to extremely important. Then, the most important factors were determined with the fuzzy Delphi technique in three rounds. This technique was applied at the level of both factors and subfactors. Here, we present the rounds and results of the fuzzy Delphi at the subfactor level. To this end, a questionnaire was first distributed among 12 experts. *Table 2* summarizes the results.

Table 2. Results of the first round of the Delphi method.

Non-Fuzzy Average of Expert Opinions	Min	Mod	Max	Very Low 1 (0,1,3)	Low 3 (1,3,5)	Medium 5 (3,5,7)	High 7 (5,7,9)	Very High 9 (7,9,10)	Linguistic Values / Numerical Values / Fuzzy Value	Component
8.09	6.20	8.20	9.52	0	0	2	6	17	Suitability of material prices to market prices	Financial factors
7.86	5.96	7.96	9.46	0	0	3	7	15	Transportation cost	
8.16	6.28	8.28	9.56	0	0	2	5	18	Product price	
7.93	6.04	8.04	9.36	0	0	4	4	17	Order Cost	
8.16	6.28	8.28	9.56	0	0	2	5	18	Defective rate	
7.94	6.04	8.04	9.44	0	0	2	8	15	Management commitment to quality	Quality factor
8.24	6.36	8.36	9.64	0	0	1	6	18	Guarantees and policies	
6.08	4.12	6.12	7.88	0	4	9	6	6	Ability to achieve abnormal quality	
7.64	5.72	7.72	9.16	0	1	3	7	14	ISO quality management system	
7.94	6.04	8.04	9.44	0	0	2	8	15	Quality guarantee	
5.07	4.08	5.08	7.00	0	9	8	6	2	System of corrective and preventive measures	
4.44	2.44	4.44	6.44	0	15	2	8	0	Process improvement	
4.28	2.28	4.28	6.28	0	16	2	7	0	Timely delivery	

Table 2. Continued.

Non-Fuzzy Average of Expert Opinions	Min	Mod	Max	(0,1,3) 1 Very Low	(1,3,5) 3 Low	(3,5,7) 5 Medium	(5,7,9) 7 High	(7,9,10) 9 Very High	Linguistic Values / Numerical Values / Fuzzy Value	Component
7.94	6.04	8.04	9.44	0	0	2	8	15	Technology level	
7.63	5.72	7.72	9.16	0	0	5	6	14	Research and development capabilities	
6.63	4.68	6.68	8.40	0	2	7	9	7	Current production capabilities or facilities	
6.79	4.84	6.84	8.52	0	2	6	9	8	Development of supplier technology for…	
7.77	5.88	7.88	9.24	0	1	3	5	16	Technology compatibility	Technology factors
4.36	2.40	4.36	6.32	1	9	13	1	1	Technological capacity	
8.29	6.32	8.40	9.80	0	0	3	6	17	Ability to prevent contamination	
8.17	6.28	8.28	9.60	0	0	1	7	17	Environmental certification such as ISO 14000	
7.94	6.04	8.04	9.44	0	0	2	8	15	Environmental productivity	
4.28	2.28	4.28	6.28	0	16	2	7	0	RoHS compliant	
3.86	1.88	3.84	5.92	3	16	2	5	0	Protection program or policy…	
8.31	6.44	8.44	9.68	0	0	1	5	19	Environmental policies	
8.24	6.36	8.36	9.64	0	0	1	6	18	Continuous monitoring and compliance	Ecology factor
7.71	5.80	7.80	9.24	0	0	4	7	14	Green process planning	
8.26	6.28	8.28	9.56	0	0	2	5	18	Check the interior	
7.85	5.96	7.96	9.32	0	0	4	5	16	Examination of the external environment	
6.01	4.04	6.04	7.84	0	5	7	8	5	Environmental constraints	
3.99	2.12	3.96	5.96	4	9	8	4	0	Pay attention to uncertainty	
8.17	6.28	8.28	9.64	0	0	0	9	16	Waste reduction	Environmental factor
7.94	6.04	8.04	9.44	0	0	2	8	15	Recycling	
7.86	5.96	7.96	9.31	0	0	3	7	15	Shopping based on products…	
6.01	4.04	6.04	7.84	0	5	7	8	5	Flexibility	

In the second round, the desinged questionnaire was prepared and sent to the experts for the second time. Collecting the distributed questionnaire and measuring the differences between average responses in first and second round, the confirmed factors were determined. The results of the calculations are presented in *Table 3*.

According to the views presented in the first stage and its comparison with the results of this stage, according to the Pareto (20/80) rule, if the difference between the two stages is less than the threshold of 0.2, then the poll process will stop. As the table above shows, some of the variables, the members of the expert group have reached a consensus and the amount of disagreement in the first and second stages was less than the threshold of 0.2, so the survey on the above variables was stopped. Among the mentioned variables, the variables that have a non-fuzzy average of expert opinions less than 8 were removed from the conceptual model of the research. The poll will continue in the third stage.

Table 3. Results of the second round of Delphi method.

Result	Differences between the Means of the First and Second Questionnaires	Non-Fuzzy Average of Expert Opinions	Min	Mod	Max	Very Low	Low	Medium	High	Very High	Linguistic Value	Component
						1	3	5	7	9	Numerical Value	
						(0,1,3)	(1,3,5)	(3,5,7)	(5,7,9)	(7,9,10)	Fuzzy Value	
Confirmed	0.07	8.16	6.28	8.28	9.56	0	0	2	5	18	Suitability of material prices to Market prices	Financial factors
Confirmed	0.15	8.01	6.12	8.12	9.44	0	0	3	5	17	Transportation cost	
Confirmed	0.15	8.31	6.44	8.44	9.68	0	0	1	5	19	Product price	
Next	0.53	8.46	6.60	8.60	9.76	0	0	1	3	21	Order Cost	
Confirmed	0.07	8.23	6.36	8.36	9.60	0	0	2	4	19	Defective rate	
Confirmed	0.15	8.09	6.20	8.20	9.52	0	0	2	6	17	Management commitment to quality	Quality factor
Confirmed	0.15	8.39	6.52	8.52	9.72	0	0	1	4	20	Guarantees and policies	
Unconfirmed	0.13	5.95	3.96	5.96	7.88	0	1	13	9	2	Ability to achieve abnormal quality	
Next	0.47	8.09	6.20	8.20	9.56	0	0	1	8	16	ISO quality management system	
Confirmed	0.07	8.01	6.12	8.12	9.48	0	0	2	7	16	Quality guarantee	
Unconfirmed	0.15	4.92	2.92	4.92	6.92	0	7	12	6	0	System of corrective and preventive measures	
Unconfirmed	0.08	4.36	2.36	4.36	6.36	0	15	3	7	0	Process improvement	
Unconfirmed	0.08	4.20	2.36	4.20	6.04	0	11	6	6	0	Timely delivery	
Confirmed	0.08	8.02	6.12	8.12	9.52	0	0	1	9	15	Technology level	Technology factors
Next Round	0.61	8.24	6.36	8.36	9.64	0	0	1	6	18	Research and development capabilities	
Unconfirmed	0.07	6.56	4.60	6.60	8.36	0	2	7	10	6	Current production capabilities or facilities	
Unconfirmed	0.07	6.71	4.76	6.76	8.48	0	2	6	10	7	Development of supplier technology for …	
Next Round	0.47	8.24	6.36	8.36	9.64	0	0	1	6	18	Technology compatibility	
Unconfirmed	0.16	4.20	2.20	4.20	6.20	0	10	15	0	0	Technological capacity	
Confirmed	0.12	8.17	6.28	8.28	9.60	0	0	1	7	17	Ability to prevent contamination	Ecological Factor
Confirmed	0.15	8.32	6.44	8.44	9.72	0	0	0	7	18	Environmental certification such as ISO 14000	
Confirmed	0.08	8.02	6.12	8.12	9.52	0	0	1	9	15	Environmental productivity	
Unconfirmed	0.08	4.20	2.20	4.20	6.20	0	15	5	5	0	RoHS compliant	
Unconfirmed	0.12	3.74	1.84	3.72	5.72	3	16	0	6	0	Protection program or policy…	
Confirmed	0.15	8.47	6.60	8.60	9.80	0	0	0	5	20	Environmental policies	

Table 3. Continued.

Result	Differences between the Means of the First and Second Questionnaires	Non-Fuzzy Average of Expert Opinions	Min	Mod	Max	Very Low 1 (0,1,3)	Low 3 (1,3,5)	Medium 5 (3,5,7)	High 7 (5,7,9)	Very High 9 (7,9,10)	Linguistic Value / Numerical Value / Fuzzy Value	Component
Confirmed	0.15	8.39	6.52	8.52	9.72	0	0	1	4	20	Continuous monitoring and compliance	
Next Round	0.46	8.17	6.28	8.28	9.60	0	0	1	7	17	Green process planning	
Confirmed	0.15	8.31	6.44	8.44	9.68		0	1	5	19	Check the interior	
Confirmed	0.16	8.01	6.12	8.12	9.48	0	0	2	7	16	Examination of the external environment	Environmental factor
Unconfirmed	0.01	6.02	4.04	6.04	7.92	0	3	9	10	3	Environmental constraints	
Unconfirmed	0.01	3.97	2.04	3.96	5.96	2	11	10	2	0	Pay attention to uncertainty	
Confirmed	0.07	8.25	6.36	8.36	9.68	0	0	0	8	17	Waste reduction	
Confirmed	0.16	8.10	6.20	8.20	9.60	0	0	0	10	15	Recycling	
Confirmed	0.15	8.01	6.12	8.12	9.44	0	0	3	5	17	Shopping based on products...	
Unconfirmed	0.16	6.17	4.20	6.20	8.00	0	3	9	8	5	Flexibility	

Survey of the third stage

In this stage, while applying the necessary changes in the model variables, the third questionnaire was prepared and sent to the experts again with the previous point of view of each person and the extent of their differences with the average views of other experts. The difference is that at this stage, 30 of the components in the previous stage were stopped and a survey was conducted on the remaining 5 components, the results of which are presented in *Table 5*.

Table 4. Results of the second round of Delphi method.

Result	Differences Between the Means of the First and Second Questionnaires	Non-Fuzzy Average of Expert Opinions	Min	Mod	Max	Very Low 1 (0,1,3)	Low 3 (1,3,5)	Medium 5 (3,5,7)	High 7 (5,7,9)	Very High 9 (7,9,10)	Linguistic Value / Numerical Value / Fuzzy Value
Confirmed	0.07	8.39	6.52	8.52	9.76	0	0	0	6	19	Order Cost
Confirmed	0.08	8.17	6.28	8.28	9.64	0	0	0	9	16	ISO quality management system
Confirmed	0.08	8.32	6.44	8.44	9.72	0	0	0	7	18	Research and development capabilities
Next round	0.15	8.39	6.52	8.52	9.72	0	0	1	4	20	Technology compatibility
Confirmed	0.07	8.09	6.20	8.20	9.56	0	0	1	8	16	Green process planning

As the table above shows, the amount of disagreement of experts in the second and third stages is less than the threshold of 0.2, and therefore the poll is stopped at this stage. The fuzzy Delphi results showed that in order of weight of criteria, out of 35 sub-factors, 12 sub-factors were removed from the final conceptual model of the research and finally there was a consensus for 5 main indicators along with 23 effective sub-indicators. Now, to the first question of the research, "what are the indicators affecting the green supply chain in the steel industry of Guilan province?" it was answered that the most important factors are identified in *Table 5*.

Table 5. Factors and sub-factors affecting the green supply chain.

Code	Sub-Factors	Factors
C_{11}	Suitability of material prices to market prices	Financial factor
C_{12}	Transportation cost	C_1
C_{13}	Product price	
C_{14}	Order Cost	
C_{21}	Defective rate	Quality factor
C_{22}	Management commitment to quality	C_2
C_{23}	Warranties and Policy	
C_{24}	ISO quality management system	
C_{25}	Quality assurance	
C_{31}	Technology level	Technology factor
C_{32}	R&D capability	C_3
C_{33}	Technology compatibility	
C_{34}	Ability to prevent contamination	
C_{41}	Environmental certification such as ISO 14000	Ecology factor
C_{42}	Environmental productivity	C_4
C_{43}	Environmental policies	
C_{44}	Continuous monitoring and compliance with regulations	
C_{45}	Green process planning ISO 14000	
C_{51}	Examination of the interior	Environmental factor
C_{52}	Examination of the external environment	C_4
C_{53}	Reduction of waste	
C_{54}	Waste recycling	
C_{55}	Purchase based on environmental products	

Finally, according to the factors and factors listed in *Table 5*, the hierarchial model was formed as follows:

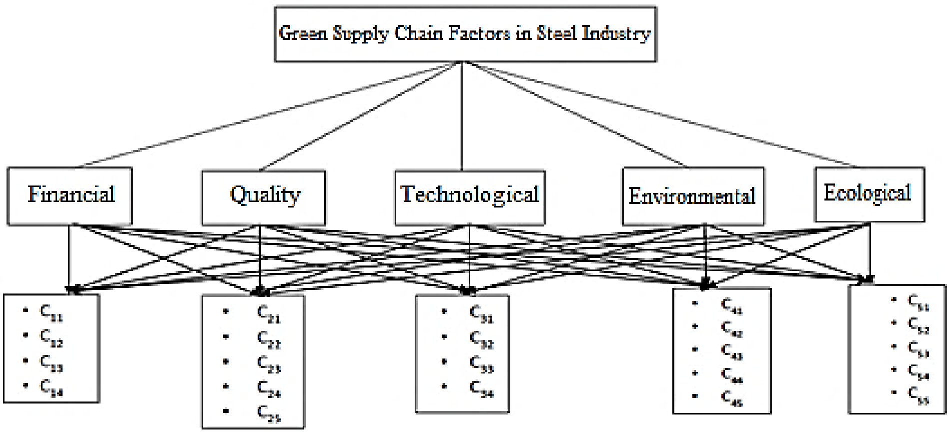

Fig. 1. Hierarchial structure of the factors.

DEMATEL solution

The sum of the elements of the columns and rows of the matrix $\tilde{T}$ are calculated for the main factors and their sub-factors and are named as vectors $\tilde{R}$ (influencing) and $\tilde{D}$ (to be oinfluenced). The calculations are mentioned in *Tables 6* and *7*.

Balaei et al.| Int. J. Res. Ind. Eng. 12(1) (2023) 73-87

Table 6. Criteria values $\tilde{R}$, $\tilde{D}$, $\tilde{R}+\tilde{D}$, $\tilde{R}$-$\tilde{D}$.

Factors	$\tilde{D}$	R	$\tilde{D}+R$	$\tilde{D}-R$	Result
Financial	0.901	1.897	2.798	-0.996	The most effective
Quality	1.293	1.321	2.614	-0.028	Effective
Technology	1.524	0.84	2.364	0.684	Effective
Ecologicy	1.096	1.548	2.644	-0.452	Effective
Enviromental	1.651	0.858	2.509	0.792	The most effective

Table 7. Non-standard values $\tilde{R}$, $\tilde{D}$, $\tilde{R}+\tilde{D}$, $\tilde{R}$-$\tilde{D}$.

Main Factors	Sub-Factors	$\tilde{D}$	R	$\tilde{D}+R$	$\tilde{D}-R$
Financial factor C_1	Suitability of material prices to Market prices	0.394	0.322	0.715	0.0717
	Transportation cost	0.392	0.355	0.747	0.0364
	Product price	0.356	0.384	0.739	-0.028
	Order Cost	0.32	0.4	0.72	-0.08
Quality factor C_2	Defective rate	0.373	0.373	0.746	0.0003
	Management commitment to quality	0.473	0.393	0.866	0.0794
	Warranties and Policy	0.355	0.346	0.701	0.0093
	ISO quality management system	0.332	0.367	0.699	-0.035
	quality assurance	0.282	0.336	0.619	-0.054
Technology factor C_3	Technology level	0.389	0.391	0.78	-0.002
	R&D capability	0.367	0.365	0.732	0.0012
	Technology compatibility	0.354	0.457	0.812	-0.103
	Ability to prevent contamination	0.364	0.351	0.714	0.0131
Ecology factor C_4	Environmental certification such as ISO 14000	0.454	0.418	0.871	0.036
	Environmental productivity	0.392	0.391	0.783	0.0004
	Environmental policies	0.444	0.432	0.876	0.0115
	Continuous monitoring and compliance with regulations	0.393	0.357	0.75	0.0367
	Green process planning ISO 14000	0.336	0.42	0.756	-0.085
Environmental factor C_4	Examination of the interior	0.355	0.312	0.667	0.0427
	Examination of the external environment	0.323	0.305	0.628	0.0179
	Reduction of waste	0.325	0.306	0.631	0.0184
	Waste recycling	0.304	0.308	0.612	-0.004
	Purchase based on environmental products	0.282	0.357	0.64	-0.075

Fig. 2 shows the importance of impact and effectiveness between criteria. The horizontal axis of the graph shows the importance of the criteria and the vertical axis shows the effectiveness of the criteria. Therefore, it can be concluded that the importance and effectiveness of the criteria are "environmental factor", "technology factor", "quality factor", "environmental factor" and "financial factor", respectively. Indicators that have a positive $\tilde{D}$-R according to *Table 4* of the value definitely show the effectiveness of these factors, and factors that have a negative $\tilde{D}$-R indicate the definite influence of these factors on other factors; Therefore, among the main factors, "environmental factor" with an impact value of 0.792 is the most effective and "financial factor" with a net impact value of -0.996 are the most effective indicators. In general, positive $\tilde{D}$-R, causal factors and negative $\tilde{D}$-R are considered effective disability factors. At this time, to the second question of the research, "what is the causal relationship (effectiveness and effectiveness) between the criteria affecting the green supply chain in the steel industry of Guilan province?" was answered. Finally, the cause-and-effect relationships are plotted by drawing points with coordinates $\tilde{D}+\tilde{R}$ and $\tilde{D}$-R based on the T matrix and the degree to which factors affect

each other in a Cartesian coordinate system. Accordingly, the cause-and-effect diagram and the map of network networks of factors are shown in *Fig. 2*.

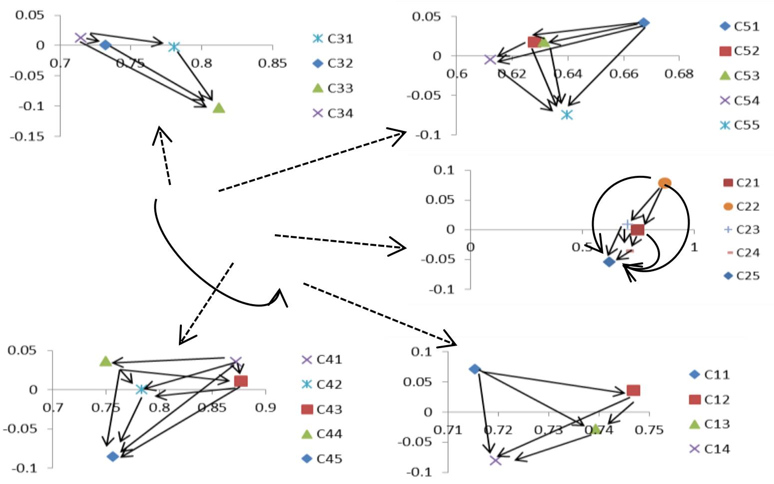

Fig. 2. Network map of the relationship between the main criteria and sub-criteria.

In this section, the structural-interpretive method is used for modeling, in which the relationship and how their effects and segregation for the green supply chain in the steel industry are determined. Problem solving in the present study with structural-interpretive method is as follows:

Table 8. Determining the levels of factors affecting the green supply chain in the steel industry.

Factors		D	R	D-R	Level	Result
Product price	4	-22	23	-22	1	dependent
Suitability of material prices to market prices	1	-18	22	-18	2	dependent
Order Cost	2	-18	22	-18	2	dependent
Transportation cost	3	-18	22	-18	2	dependent
Defective rate	8	-13	19	-13	3	dependent
Quality assurance	9	-13	19	-13	3	dependent
Environmental productivity	15	-9	17	-9	4	dependent
Green process planning ISO 14000	18	-9	17	-9	4	dependent
ISO quality management system	5	-4	15	-4	5	dependent
Management commitment to quality	7	-4	15	-4	5	dependent
Environmental certification such as ISO 14000	16	-4	15	-4	5	dependent
Warranties and Policy	6	2	12	2	6	free
Continuous monitoring and compliance with regulation	14	2	12	2	6	free
Environmental policies	17	2	12	2	6	free
Ability to prevent contamination	10	7	9	7	7	Independent
Technology compatibility	12	7	9	7	7	Independent
R& D ability	11	11	7	11	8	Independent
Technology level	13	11	7	11	8	Independent
Reduction of waste	20	16	5	16	9	Independent
Waste recycling	22	16	5	16	9	Independent
Purchase based on environmental products	23	16	5	16	9	Independent
Examination of the external environment	19	21	2	21	10	Independent
Examination of the interior	21	21	2	21	10	Independent

After determining the relationships and level of variables, they can be drawn as a model. For this purpose, we first adjust the variables in descending order according to their level. In the present study, the factors are in 10 levels. *Fig. 3* shows the model of interpretive structure to separate the effective factors of green supply chain in the steel industry.

Balaei et al.| Int. J. Res. Ind. Eng. 12(1) (2023) 73-87

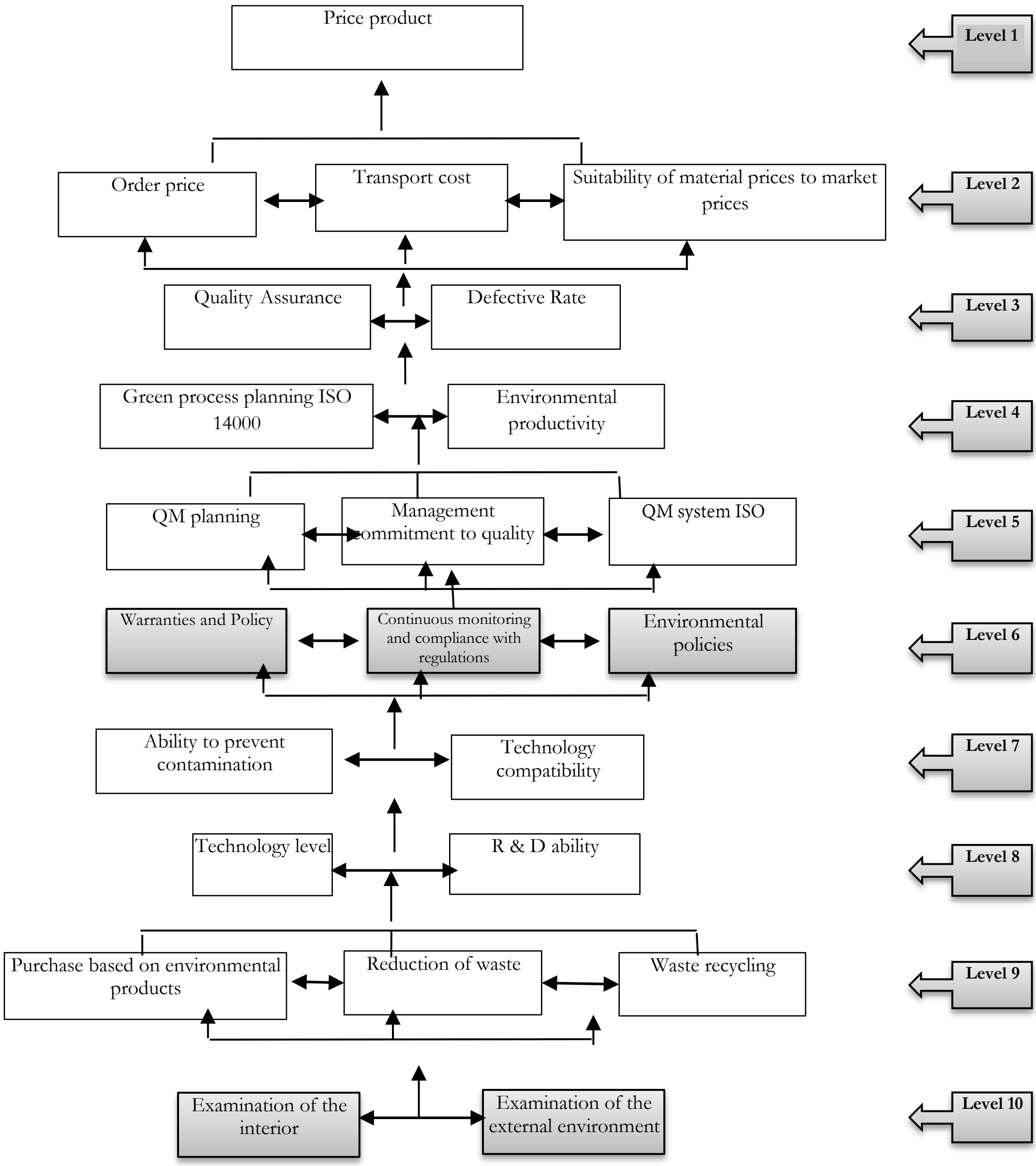

Fig. 3. Interpretive-structural model for green supply chain in steel industry.

At the highest level of the model (Level 10) there are two factors "external environment study" and "internal environment study" that act as the foundation of the model that the green supply chain in the steel industry starts from these factors and spreads to others. The factors "waste reduction", "waste recycling" and "purchasing based on environmental products" are at level 9. These variables are interrelated and affect their next levels. These factors are affected by the previous level and affect the next level factor. In the second level, there are three factors "suitability of material price to market price", "order cost" and "shipping cost", which in addition to affecting the first level, also have internal relations with each other. The second level factors affect the first level factors of "product price" which leads to the green supply chain. The "product price" factor is a component that is the result of other factors planned in the green supply chain.

4 | Conclusions

The first purpose of this study was to identify the factors affecting the green supply chain in the steel industry, especially Guilan Steel Company. According to the research conducted in the field of research and after screening, 23 important factors were identified, the main criteria of which are "financial, quality, technology, environmental and environmental" factors, which are in line with the first goal of the research.

The second purpose of the study was to determine the relationships and effects of factors on each other. To achieve this goal, the fuzzy DEMATEL technique was used. The results of this technique are described as follows: "Financial factor" is the most influential factor in the green supply chain in the steel industry. In other words, this factor is the main problem and bottleneck of improving the supply chain design in the organization, which is solved by influential factors. In fact, the success or failure of the green supply chain depends on this factor; therefore, it can be concluded that in order to achieve organizational productivity, the organization must be in the green supply chain to the financial factor and so on. Note. This finding is in line with the findings of researchers such as Malviya and Kant [15], Chand et al. [21], Govindan et al. [22], Kannan et al. [23], Wang et al. [24] and so on. "Environmental factor" is also the most influential factor in the green supply chain. In other words, it is the criterion that is most important and solves the problem and should be prioritized to improve the system. It can be concluded that environmental factors have a significant impact on the green supply chain. Also, the management factor can increase the efficiency and improve processes, etc. can be an effective factor in the green supply chain and its use in the organization. This finding is in line with the findings of Malviya and Kant [15], Tseng et al. [25], Azad [26], Yazdani et al. [27], Ansari and Sadeghi Moghaddam [28] and etc.

According to the ISM, two factors, "external environment study" and "internal environment study" are at the highest level of the model and we should try to use the intensity of this criterion to strengthen the system. Therefore, it is recommended to the senior managers of the organization and the decision-making department of the steel industry, especially steel of Guilan province (private joint stock company) by reducing the price of the product, reducing the cost of transportation, improving the cost of ordering, the appropriateness of material prices to market prices. They should try to maintain their competitive position and should try to make the company under study successful with suggestions. Because the success or failure of the company is to this criterion (the most effective) and we should try to use the intensity of penetration of this criterion to strengthen the system. Therefore, senior managers and decision-makers of the steel industry, especially steel in Guilan province (private joint stock company) are advised to try to further reduce waste and such cases to increase and maintain their competitive position by using the study of the external environment and the study of the internal environment.

The Main limitation of the research was the lack of access to experts during office hours, so an attempt was made to get experts judgments out of the work hours. The other limitation of the research is arised from the diversification of the green supply chain factors which needs to comprehensive research in such as literature review. For conducting the future studies, in recommends to researchers to study the green supply chain papers and deeply investigate its factors, drivers, obstacles, threats, and etc and teoritically contribute on this literature. Also, the qualitative modelling methods such as theme analysis, grounded theory and similar methods are recommended to use as conceptualization of this scope.

Acknowledgments

The Authors acknowledge the managers and employees of Guilan Steel Industry.

Conflicts of Interest

All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

References

[1] Haldar, S., Karmaker, C. L., & Hossain, S. R. (2018). A framework to evaluate and improve supply chain: FAHP based case study on a supermarket. *International journal of research in industrial engineering*, *7*(4), 423-440.

[2] Zahedi, M., & Ghahremani Nahr, J. (2021). Modeling of the supply chain of cooperative game between two tiers of retailer and manufacturer under conditions of uncertainty. *International journal of research in industrial engineering*, *10*(2), 95-116.

[3] Nasiri, A., Mansory, A., & Mohammadi, N. (2022). Evaluating of effective factors on green supply chain management using statistical methods and SWARA approach. *International journal of research in industrial engineering*, *11*(2), 165-187.

[4] Mokhtari Karchegani, F., Shirouyehzad, H., & Tavakkoli-Moghaddam, R. (2015). A multi-objective model for location-allocation problem in a supply chain. *International journal of research in industrial engineering*, *4*(1-4), 24-42.

[5] Barzegar, M., Ehtesham Rasi, R., & Niknamfar, A. H. (2018). Analyzing the drivers of green manufacturing using an analytic network process method: a case study. *International journal of research in industrial engineering*, *7*(1), 61-83.

[6] Habiba, U., Ripon, B. M., & Islam, M. D. (2021). Optimization of a green supply chain network: a case study in a pharmaceutical industry. *International journal of research in industrial engineering*, *10*(3), 174-186.

[7] Delshad, Z., & Babaei Meybodi, H. (2018). Dynamic modeling of systems to evaluate the factors affecting green supply chain management. *Biannual journal of value chain management*, *2*(6), 51-62. (**In Persian**). https://journals.iau.ir/article_659965.html

[8] Mohammad, P., & Kazemipoor, H. (2020). An integrated multi-objective mathematical model to select suppliers in green supply chains. *International journal of research in industrial engineering*, *9*(3), 216-234.

[9] Raut, R. D., Luthra, S., Narkhede, B. E., Mangla, S. K., Gardas, B. B., & Priyadarshinee, P. (2019). Examining the performance oriented indicators for implementing green management practices in the Indian agro sector. *Journal of cleaner production*, *215*, 926-943. https://doi.org/10.1016/j.jclepro.2019.01.139

[10] Attar, M., Gilaninia, S., & Homayounfar, M. (2016). A study of the effect of green supply chain management's components on the performance of the pharmaceutical distribution companies system in Iran. *Oman chapter of Arabian journal of business and management review*, *5*(8), *48-54*.

[11] Nozari, H., Fallah, M., & Szmelter-Jarosz, A. (2021). A conceptual framework of green smart IoT-based supply chain management. *International journal of research in industrial engineering*, *10*(1), 22-34.

[12] Homayounfar, M., & Daneshvar, A. (2018). Prioritization of green supply chain suppliers using a hybrid fuzzy multi-criteria decision making approach. *Journal of operational research in its applications (applied mathematics)-Lahijan Azad University*, *15*(2), 41-61.

[13] Rezaee Kelidbari, H. R., Homayounfar, M., & Alavi Foumani, S. E. F. (2016). A combined group ea-promethee method for a supplier selection problem. *Iranian journal of optimization*, *8*(2), 87-100.

[14] Laari, S., Töyli, J., Solakivi, T., & Ojala, L. (2016). Firm performance and customer-driven green supply chain management. *Journal of cleaner production*, *112*, 1960-1970. https://doi.org/10.1016/j.jclepro.2015.06.150

[15] Malviya, R. K., & Kant, R. (2017). Modeling the enablers of green supply chain management: an integrated ISM–fuzzy MICMAC approach. *Benchmarking: an international journal*, *24*(2), 536-568.

[16] Ishikawa, A., Amagasa, M., Shiga, T., Tomizawa, G., Tatsuta, R., & Mieno, H. (1993). The max-min Delphi method and fuzzy Delphi method via fuzzy integration. *Fuzzy sets and systems*, *55*(3), 241-253.

[17] Wu, W. W. (2012). Segmenting critical factors for successful knowledge management implementation using the fuzzy DEMATEL method. *Applied soft computing*, *12*(1), 527-535.

[18] Zhou, Q., Huang, W., & Zhang, Y. (2011). Identifying critical success factors in emergency management using a fuzzy DEMATEL method. *Safety science*, *49*(2), 243-252.

[19] Sharifi, A., & Homayounfar, M. (2016). An analysis of factors affecting on customers' adoption of internet-banking services using the graph theory. *Iranian journal of optimization*, *8*(1), 47-58.

Balaei et al. | Int. J. Res. Ind. Eng. 12(1) (2023) 73-87

[20] Beikkhakhian, Y., Javanmardi, M., Karbasian, M., & Khayambashi, B. (2015). The application of ISM model in evaluating agile suppliers selection criteria and ranking suppliers using fuzzy TOPSIS-AHP methods. *Expert systems with applications*, *42*(15-16), 6224-6236.

[21] Chand, M., Bhatia, N., & Singh, R. K. (2018). ANP-MOORA-based approach for the analysis of selected issues of green supply chain management. *Benchmarking: an international journal*, 25(2), 642-659.

[22] Govindan, K., Kaliyan, M., Kannan, D., & Haq, A. N. (2014). Barriers analysis for green supply chain management implementation in Indian industries using analytic hierarchy process. *International journal of production economics*, *147*, 555-568.

[23] Kannan, D. Govindan, D. & Rajendran, S. (2015). Fuzzy Axiomatic Design approach based green supplier selection: a case study from Singapore. *Journal of cleaner production*, 96(1), 194-208.

[24] Wang, Z., Subramanian, N., Gunasekaran, A., Abdulrahman, M. D., & Liu, C. (2015). Composite sustainable manufacturing practice and performance framework: Chinese auto-parts suppliers' perspective. *International journal of production economics*, *170*, 219-233.

[25] Tseng, M. L., Tan, K. H., Lim, M., Lin, R. J., & Geng, Y. (2014). Benchmarking eco-efficiency in green supply chain practices in uncertainty. *Production planning & control*, *25*(13-14), 1079-1090.

[26] Azad, S. (2017). The application of structural interpretive modeling to empower green supply chain management: the case of Iran Khodro. *Proceeding of 8th international conference of management and accounting and 5th conference of entrepreneurship and open innovations*, Tehran University Press, Tehran. (**In Persian**). https://civilica.com/doc/676425/

[27] Yazdani, N., Sardari, A., & Omidvar, R. (2015). Ranking barriers to green supply chain management using DIMATEL. *New marketing research journal*, *5*(2), 1-14. (**In Persian**). https://nmrj.ui.ac.ir/article_17786.html?lang=en

[28] Ansari, I., & Sadeghi Moghaddam, M. (2014). Identification and determination of the relations and categorization of green supply chain management incentives with a structural-interpretive modeling approach. *Industrial management studies*, *12*(35), 123-150. (**In Persian**). http://ensani.ir/fa/article/download/340925