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Integrated QFD-MCDM framework for green supplier selection

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ABSTRACT

Supplier evaluation and selection is a significant strategic decision for reducing operating costs and improving organizational competitiveness to develop business opportunities. Moreover, with increasing concern towards environmental protection and sustainable development, it becomes important to pay more attention to environmental requirements and evaluating the potential suppliers by incorporating green factors into the selection process. Thus, the aim of this paper is to put forward an integrated approach for green supplier selection by considering various environmental performance requirements and criteria. The proposed approach addresses the inter-relationships between the customer requirements (CRs) with the aid of decision-making trial and evaluation laboratory (DEMATEL) method while constructing a relationship structure. Quality function deployment (QFD) model is used to establish a central relationship matrix in order to identify degree of relationship between each pair of supplier selection criteria and CRs. Finally, complex proportional assessment (COPRAS) applied to prioritize and rank the alternative suppliers. A case study is presented to reveal the potentiality and aptness of the proposed methodology.

1. Introduction

Supply chain management (SCM) is a process of systematizing and amalgamating diverse activities, starting from the customer's order to end product delivery in a well-organized manner. The success or failure of any SCM largely depends upon a suitable system and appropriate suppliers. Today's fast changing SCM environment is characterized by low profit boundary, high quality expectations with less waiting time for orders (Ke et al., 2015) Even over the last two decades the world economy has been spectacularly changed due to a variety of reasons. Modern day's business environment is frequently distinguished by increasing intricacy, ambiguity, unsteadiness and unpredictability. Thus, organizations must take each and every opportunity to advance their operational performance to stay competitive in the worldwide marketplace by appropriately selecting its trading partners.

In a supply chain network (SCN), supplier evaluation and selection is a deliberated task because of high complications with several conflicting, commensurable, ordinal and cardinal factors involved in the decision-making process (Yazdani et al., 2016). In this network, organizations are forced to harmonize their purchasing activities in order to gain advantage. In managing purchasing activities proficiently, supplier evaluation and selection plays a crucial role and has become a very fundamental component for viable benefits of any organization (Rezaei et al., 2014). In addition, selecting suitable suppliers considerably reduces material purchasing cost, increases flexibility and product quality and eventually helps to accelerate the process of material purchasing. The main objectives of supplier selection are thus to reduce the risk of purchasing and development of a long-term relationship between buyer and supplier (Omurca, 2013).

Mostly, there are two aspects in the context of supplier evaluation and selection. Evaluation of suppliers depends on several criteria. Some criteria such as price, quality, delivery performance, branding or reputation are frequently selected for comparison and

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assessment (Rajesh and Ravi, 2015). Traditional studies on supplier selection have concentrated broadly on relevant supplier selection methods and criteria without considering the voice of the customers or customer requirements (CRs). However, for an efficient SCM, establishing a clear understanding about customers' needs, specifically their subjective performance requirements play a vital role. Also, large portion of these studies have evaluated suppliers under economic criteria such as cost, flexibility and delivery rather than highlighting buyer satisfaction and characteristics related to the supplier's criteria. Consequently, there is a lack of connecting supplier evaluation criteria to the CRs which are prerequisites to be fulfilled for the benefit of the stakeholders.

It is observed that the previous studies have put concentrations only on economic efficiency of suppliers rather than ecological efficiency and rarely noticed and took into account the environmental issues to the supplier selection studies (Kumar et al., 2014). Environmental deteriorations have forced public and private sectors to think over environmental and sustainable issues. To survive in the global market in wake of developing competition, and due to the increased awareness about environmental concerns, green supply chain management (GSCM) is appearing in recent literature (Govindan et al., 2013; Bai and Sarkis, 2010; Khaksar et al., 2016). Since major components of an end product are supplied by the external suppliers, hence it becomes important to pay more attention to environmental requirements in the supply chain process and evaluating the potential suppliers by incorporating green criteria into the selection process (Kannan et al., 2014). Importance of environmental sustainability in an SCM highly depends on the purchasing strategies and its suppliers. Since the supplier selection process is analyzed as a combination of CRs and technical requirements (TRs) or supplier selection criteria. Therefore, supplier relation can be observed as a house of quality (HoQ) model that seeks to categorize which of the supplier's attributes have the greatest impact on the attainment of its established goals.

This paper aims at developing an integrated approach for evaluating supplier performance and selecting the best supplier while considering both traditional and green supplier selection criteria simultaneously. An attempt is made to evaluate and rank ten alternative green suppliers for a reputed Iranian dairy company using the integrated approach consisting of decision-making trial and evaluation laboratory (DEMATEL), quality function deployment (QFD) model, complex proportional assessment (COPRAS) (Zavadskas et al., 1994; Hashemkhani Zolfani et al., 2012) and multi-objective optimization on the basis of ratio analysis (MOORA) (Brauers and Zavadskas, 2006, 2009) methods.

The contribution of our proposed model is some folds; causal relationship and interaction level between the CRs and supplier selection criteria are addressed using DEMATEL method, and the most important CR having significant influence on the remaining CRs is also identified. QFD provides the weights of the evaluating criteria, which are derived by the degree of relationship between CRs and evaluating criteria. MOORA and COPRAS methods are applied to prioritize and compare the green suppliers. We have brought up a real case study of a famous dairy company in Iran to implement the proposed model and guide managers to a clearer understanding of customer standards and regulations. The adopted multi-criteria approach can assist the decision makers (DMs) to directly assess the attributes according to their prominence degree while providing a ranking preorder to all the alternative suppliers. The proposed integrated approach would be more realistic and practical particularly in supplier selection domain and generally with respect to any complex decision-making situations.

Rest of paper interprets the following sections: section 2 describes literature review including traditional and green supplier selection requirements and criteria, solo and integrated approaches for supplier selection problems and tools and techniques for selecting green suppliers. In Section 3, research significance is addressed. Section 4 presents the proposed integrated framework for green supplier selection. Section 5 illustrates an example on green supplier selection to validate the proposed integrated model. The results and discussions and managerial implications are also presented in this section. Section 6 concludes the paper. Appendix includes all the required methods and formulas.

2. Literature review

This section presents a brief review of literature on traditional and green supplier selection criteria and traditional and green supplier selection methods. Both green and sustainable supplier selection are common research in SCM framework of study. Sustainability is a bigger picture of strategies for managing the world from different aspects but in level of companies. Green supplier selection can be considered as the vital part of bigger picture, sustainability. The environment is the main part of sustainable supplier selection and its dimensions (Liou et al., 2016). The main act of companies which can be useful in bigger structure is actions about the environment. This research is established in companies' level and their activities. The bigger picture is out of scope for this research. Sustainable Supply Chain Management (SSCM) should be considered in regional, national and international policies and strategies with a clear vision.

It has become increasingly imperative for organizations facing competitive, regulatory and community pressures to search for a balance between economic and environmental performance. Presently, many organizations are putting efforts to go green in their businesses due to their apprehension for ecological sustainability (Liao et al., 2015). Activities comprised in GSCM are re-use, recycle, remanufacture and reverse logistics etc. Lu et al. (2007) addressed materials, energy, solid residue, liquid residue, gaseous residue, and technology as the fundamental environmental criteria. Tuzkaya et al. (2009) recognized pollution control, green product, green process management and environmental and legislative management as the most significant GSCM criteria. Awasthi et al. (2010) proposed 12 environmental criteria including use of environmental friendly technology, use of environmental friendly material, partnership with green organization, green market share, management commitment, adherence to environmental policies, green R&D projects, staff training and etc.

The need for environmental practices in the food supply chain is becoming acute. The food industry currently has to contend with multiple competing pressures alongside the new challenges of green production, particularly, where the focus of attention is on environmental and greening supply chains, organizations are more concerned (Marsden et al., 2000).

Environmental and green development in dairy industry is becoming one of the most prominent topics of our time (Patzelt and Shepherd, 2011; Gimenez and Tachizawa, 2012). Glover et al. (2014) investigated on the environmental impact of the whole supply chain. Recent food crises have increased consumer awareness of the impact on public health of food production, processing, and distribution in all over the world (Van Kleef et al., 2006). Consumers have become more critical and tend to be informed about the processes of food procurement, safety levels, production methods, hygiene, security of transportation, and other environmental issues like carbon footprints (Redmond and Griffith, 2003). Nowadays, consumers include factors like quality, safety and environmental conformity in their buying decision. Managers in the food industry and dairy companies will have to respond to these changing consumer demands by increasing environmentally protection of processes and products (Wognum et al., 2011).

Environmental impact of food production has put pressure on food companies to improve the efficiency of business management. This requires cooperation between all actors in a food supply chain since ultimately the consumer at the end of the chain decides on the premium which is granted for all the efforts (Jones, 2002).

Dairy supply chain is an economically important aspect of agriculture with international aspects to its supply chain. In the dairy sector, organizations range in size both at each segment of, and across, the supply chain. The industry is highly regulated and there have been a number of environmental legislations and standards introduced over the last few years from both national, European and international directives (Dries et al., 2009; Yu and Huatuco, 2016). The dairy industry has also received high profile environmentally related attention in relation to GHG emissions from cattle (methane). These kinds of standards and legislations obligate dairy companies to control, observe, and measure all the environmental activities. Zhu and Sarkis (2006) believed supplier environmental drivers and responsibility can directly affect the whole supply chain performance.

There is far less research that addresses the relationship between a dairy company environmental strategy, its internal integration in the form of the supply chain environmental assessment and the external integration with stakeholders, customers and suppliers.

We explore what stakeholders across the diary supply chain need in order to increase supply chain efficiency in the context of supplier evaluation. Developing a supplier selection strategy to satisfy government pressures and international standard requires a blend of competitive advantage, requiring superior firm resources and capabilities as well as a fit between the external environment and interval actions. Large firms can use their strong strategies to help improve good environmental and social practices across the supply chain.

This paper focuses attention on environmental and green factors which are often related to waste reduction, pollution reduction, energy efficiency, emissions reduction, and a decrease in the consumption of hazardous materials.

Suppliers are defined as one of the vital parts of an organization who deliver all the requirements for producing complete product from raw materials, components and services and a suitable supplier is the one who meets these requirements at the right time, acceptable quality and standards. In an SCN, working with efficient suppliers enhances the productivity and profitability of any organization (Awasthi and Kannan, 2016). The process of assessment and evaluation of suppliers lies in the context of supplier selection domain. This selection process originally includes several factors, feathers, models, and methods and is called a decision-making process in the presence of multiple criteria and alternatives. From the literature survey (Refer to Table 1), it is observed that many past researchers have already subjected a pool of methods and wide range of combined approaches to evaluate and choose appropriate suppliers (Govindan et al., 2015). Integration of MCDM methods provides different approaches with particular functionalities and characteristics. Therefore, it is the art of the DMs to integrate, combine, hybridize and extend MCDM methods for specific objectives and requirement perspectives. It is also found that most of the previous attempts by the past researchers for traditional as well as green supplier selection problems have several disadvantages too (Chan and Wang, 2013; Aliev, 2013; Kahraman and Öztayşi, 2014). Moreover, no endeavor has been projected till date to present a sound mathematical model for solving green supplier selection problems which considers the interaction between the CRs and supplier selection criteria respectively. Thus, in this paper, a humble effort is taken to balance this space by proposing an integrated analytical approach for selecting green suppliers strategically consisting of DEMATEL, QFD, and COPRAS methods.

3. Research significance

As stated earlier, the supplier selection process is analyzed as a combination of customer criteria and technical requirements (supplier criteria). In a food-based production company valuing specific need and attitude of customers can be a spectacular point which can raise its competitive and strategic advantage. Although many studies addressed the influence of customer satisfaction indices and engineering features on the supplier selection process, to the best of our knowledge, none of them dealt with a systematic evaluation of how these variables interact each other. In addition, the literature on green performance measurement of supplier is tremendous (Govindan et al., 2015) a significant gap regarding to a systematic analysis of green supplier is obvious (Cuthbertson and Piotrowicz, 2008).

To bridge this gap, it is necessary to link green constructs and sub-constructs of SCM and all the inter-organizational elements contributing to the performance measurement (Bhattacharya et al., 2014).

The proposed integrated framework aims at bridging both gaps highlighted above by providing a systematic analysis of the interdependencies existing among costumer variables and technical supplier criteria. This analysis allows not only to identify a clear

Table 1
Summary of previous researches on green supplier selection methods.

Author(s)	Methodology applied	Application domain
Lu et al. (2007)	AHP	electronics industry
Tuzkaya et al. (2009)	F-ANP and PROMETHEE	manufacturing industry
Lee et al. (2009)	Delphi and Fuzzy extended AHP	high-tech electronics industry
Hsu and Hu (2009)	ANP	electronic industry
Awasthi et al. (2010)	F-TOPSIS	logistics
Kuo et al. (2010)	ANN and DEA	digital camera manufacturing in Taiwan
Kannan et al. (2013)	F-AHP, F- TOPSIS and MOLP	automobile manufacturing company
Shen et al. (2013)	Fuzzy TOPSIS	auto industry
Kannan et al. (2014)	Fuzzy TOPSIS	Brazilian electronics company
Zhao and Guo (2014)	F-Entropy and TOPSIS	thermal power equipment
Rostamzadeh et al. (2015)	Intuitionistic fuzzy VIKOR	manufacturing industry
Azadnia et al. (2015)	Rule-based weighted fuzzy method, F-AHP and MOMP	packaging films in food industry
Hashemi et al. (2015)	ANP and improved GRA	automotive industry
Kannan et al. (2015)	Fuzzy Axiomatic design	plastic manufacturing
Fallahpour et al. (2016)	Date envelopment analysis, Gene expression programming	textile company
Yazdani et al.(2016)	QFD and SWARA	automobile industry
Govindan and Sivakumar (2016)	Fuzzy TOPSIS and MOLP	paper industry
Luthra et al. (2017)	AHP and VIKOR	automobile industry -India

hierarchical structure for the all the relevant sustainable factors and sub-factors, but also to weight the decision criteria based on the importance given to customer requirements.

Attentions to integrate several techniques and convey a meaningful logic for assessing suppliers' performance are enhancing (Labib, 2011). Several contributions to green supplier selection have been obtained by employing MCDM tools (Bottani and Rizzi, 2008; Chen and Wang, 2009; Awasthi et al., 2010; Tavana et al., 2016). However, developing supplier selection decision making approaches through integrated methods can be very synergic since every specific method involves generic functions that allow for stable solutions only if suitably integrate together.

As it is a typical process for every MCDM problem, selecting the best suppliers is underlined to some essential objectives including determining the degree of importance (weight) of the selection criteria and evaluating the suppliers respecting to these criteria (Ordoobadi, 2009). In this study, we develop a case-focused model where these objectives are attained through an integrated MCDM model. Firstly, all the relevant factors/criteria assigned to suppliers and customers are defined. The main factors are interpreted as costumer requirements (CRs) and used to identify the technical requirements (TRs) necessary to weight the suppliers. Secondly, DEMATEL and QFD are integrated to determine the weights of all the criteria introduced. To the best of our understanding, our choice of handling DEAMETL to evaluate the interaction relationship between different variables of a complicated system to establish direct and indirect causal relationships and influence levels among the customer variables through is also novel to the literature. Thereafter, QFD is used to build a central relationship matrix in order to identify degree of relationship between each pair of supplier selection criteria and CRs. Then, pairwise comparison matrices are composed to evaluate each supplier with respect to each supplier selection criterion to construct corresponding supplier rating matrix. Finally, MOORA and COPRAS methods are applied and then compared to select the best alternative green supplier.

4. Proposed integrated framework for green supplier selection

The main contribution of our approach from the technical viewpoint is the way it combines DEMATEL and QFD. One of the essential tasks in MCDM modeling is seeking new and logical ways to weight decision factors (attributes). Usually, fuzzy linguistic variables, AHP, ANP, and entropy are employed to determine the weights of all the factors. However, in many decision problems the reliability of the decision criteria is strictly dependent on the stakeholders and customers' preferences. The DEMATEL-QFD phase of the proposed method provides a simple to implement costumer-dependent weighting method for decision criteria, which plays a fundamental role in situations where the satisfaction of external stakeholders and customers enter the decision process. All the methods are appeared in Appendix for more information. To figure out the whole proposed framework, see the following phases (Proposed four-phase method):

In this section we outline the phases composing the integrated framework that we propose for solving the green supplier selection problem considered in the case study.

4.1. *Phase I: identifying all relevant sustainable factors (customer and technical requirements)*

In this phase, the relevant green and environmental factors/criteria are selected considering the cited literature and the specific features of the company of the case under analysis. Experts from the company are consulted to gather information and data in order to identify the right sustainable factors and sub-factors. Two kinds of factors are collected as a result of these consultations: customer requirements (CRs) and technical requirements (TRs).

The CRs are the costumer variables, that is, the criteria on which the costumers will base their choice. The TRs include all the criteria to rank the candidate suppliers, that is, all the criteria that must be considered for the CRs to be satisfied. The TRs are the HOWs in QFD.

4.2. *Phase II: weighting customer and technical requirements*

This phase consists of two sub-phases as:

4.2.1. *Phase II.1*

The CRs are assigned a global weight using DEMATEL method to acquire a perceptive relationship between the supplier selection criteria and CRs causally and visually.

4.2.2. *Phase II.2*

The normalized prominence values of DEMATEL are considered as the weights of the respective CRs which will be further used for QFD-based analysis. These weights are used in QFD to weight the TRs.

For the sake of completeness, recall that QFD transformations are usually represented by a matrix, known as *house of quality* (HoQ). This matrix expresses the relationship between the CRs (WHATs) and the TRs (HOWs) incorporating the following items: A) WHATs matrix, B) HOWs matrix, C) relationship matrix between WHATs and HOWs, D) relative importance or weights of WHATs, E) interrelationship between HOWs, and F) weights of HOWs (Tang et al., 2005). More details on how QFD works has been given in previous comment (Fig. 1).

In the first sub-phase, a questionnaire is conducted by purchasing department experts to collect the data to input in the comparison matrices of DEMATEL and, hence, determine the global weights of all the CRs. In the second sub-phase, another questionnaire is conducted to construct the HoQ matrix where the CRs are connected to the TRs. In this questionnaire, judgments are requested on how each decision criterion is influenced by the customers' sub-factors and vice versa. The relationships composing this matrix are evaluated using a 1,3,6, and 9 scale.

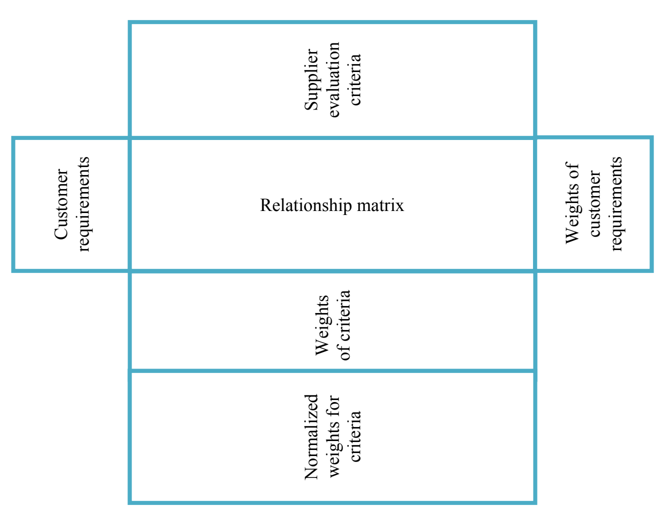

Fig. 1. QFD process for green supplier selection problem.

4.3. *Phase III: ranking the suppliers per each technical requirement*

In this phase, a questionnaire is conducted by purchasing department experts to determine the performance rating of candidate suppliers. The data collected using this questionnaire is used for the comparison matrices relative to each TR. The questions aim at establishing how much one of the suppliers is preferred to another one with respect to each specific decision criterion (TR). The pairwise comparisons are carried out using again the 1–9 scale.

4.4. *Phase IV: ranking the suppliers with COPRAS and MOORA*

In this phase, COPRAS and MOORA (See Appendix) are applied to rank the candidate suppliers. To implement these methods, both the weights of all the TRs from phase two and the supplier rankings (one per each of the TRs) obtained in phase three are needed.

For the sake of completeness, recall that the solution process of both COPRAS and MOORA starts with a $t \times n$ matrix whose generic element is the performance rating of the k-th supplier ($k = 1,\ldots,t$) upon the j-th decision criterion ($j = 1,\ldots,n$). The elements of this matrix are then normalized and used to calculate the total performance index of each supplier. The two methods differ in the normalization procedure and in the way the evaluation of the total performance of the single suppliers is carried out. COPRAS is applied to rank the suppliers. The resulting ranking is used to verify and validate those obtained in Phase IV.

In MCDM problems, it is customary to compare the results obtained by using a second method as a "mediator". In this study we use the COPRAS method due to its capability in managing complex decision systems. Developed by Zavadskas et al., 1994 and Zavadskas et al. (2007), this method has the ability of accounting for both positive (beneficial) and negative (non-beneficial) criteria, which can be assessed independently within the evaluation process. The most important feature that makes the COPRAS method superior to other methods is that it can be employed to estimate the utility of alternatives indicating the extent to which one alternative is better or worse than the other alternatives (Hashemkhani Zolfani and Bahrami, 2014). Further details on COPRAS and MOORA (Brauers and Zavadskas, 2011) are given in Appendix C and D.

5. Case study: selecting green supplier for an Iranian dairy company

5.1. *Short introduction of case study*

The proposed framework for green supplier selection is implemented within procurement and logistics department of Kalleh Dairy Company, established in 1991 in Amol, Iran. It has with more than 23 years of experience in diverse types of dairy, meat, and beverage and food products. Kalleh dairy products contain classification of UHT processed milk, yoghurt, cheese, dairy drinks, industrial dry milk, industrial powders production, buttermilk and desserts which compose more than 150 types of products. Procurement segment of Kalleh Dairy Company, called POLE, is in charge of providing wide range of raw materials and packaging at the right time, with the least price and the desired quality. Furthermore, POLE is responsible for purchasing the whole equipment required for the company, including machinery, spare parts, technical parts, laboratory equipment and material-handling equipment. To meet the production requirements, POLE deals with a wide range of domestic and foreign suppliers. It also fulfills a complete procurement process, involved sourcing, purchasing, importing and customs releasing, warehousing, maintaining and delivering of goods. The company is encouraging suppliers to utilize recyclable materials, establishing automatic pollution control systems using green and efficient energies, increasing top management commitment etc. Therefore, to assure that all suppliers perform appropriately, it is required to establish a proper supplier selection methodology. In this paper, to build a comprehensive supplier selection structure, eight CRs and seven evaluation criteria are identified from the literature survey. Financial stability (FS), environmental management systems (EMS), waste disposal program (WDP), management commitment (MC), quality control systems (QCS), manufacturing (M), facility (F) and reverse logistics (RL) are considered as CRs, whereas, quality adaptation (QD), price (P), energy and natural resource consumption (ENRC), delivery speed (DS), green design (GD), re-use and recycle rate (RRR) and production planning (PP) are recognized as supplier selection criteria. Among the seven criteria, P and ENRC are considered as cost criteria and rest of all is regarded as beneficial criteria.

The company has identified alternative suppliers for the analysis. Among suppliers, they provide packaging raw materials, raw milk and, supply milk powders and additional ingredients as sugar, salt, stabilizer and essence. Among these suppliers A_5, A_2, A_7 are in business for years and they are very flexible in delivery, cooperation and collaboration in rejection of cartoons, nylons and plastic glasses. They are planning to stablish a waste management system in their company. A_2 is a supplier with modern and high tech facilities and very respectful human resource system. Although the cost of their products seems higher than similar suppliers in their range, its capability convinces purchasing manager to keep contact them. A_1 and A_6 and A_{10} produce packaging wraps which are used for covering or forming the final products like sleeve and shrink, paper labels, vacuum films, Aluminum foils, laminate foils, sealed caps and PET caps, three layer and laminated cartons. A_3 and A_9 are in charge of supplying raw milk. This is the key raw material for dairy products, and due to the quality sensitivity and high deterioration rate; it needs the specific infrastructure of supply, transportation, and storage. Mostly quality of products like posturized and homogenized milk is measured by the quality of raw milk, and the amount of vitamins and proteins. A_8 supplier delivers good quality raw milk among others. It should be expressed that Milk powder products are widely used in dairy industry. Milk powder is generally consumed as a substitute of fresh milk and, in confectionaries and bakeries to provide desired flavor and color, and to enhance nutritional values. Whey Powder is used to produce products such as snack and chips.

Iran is faced to new paradigm and strategy about the environment. In climate change conference (2015) in Paris, Iran committed and dedicated a policy for decreasing CO_2 up to 12% till 2030. These days selecting green suppliers as a bigger vision for the future seem more necessary in comparison to the past. This fact is not far from reality because processes of so many actions in Iran aren't professionally and compatible with the environment. Technologies are almost old and new investments should be considered for general economic structure of Iran. In the near future companies will have to be well-matched with new regulations and standards in the near future. Kalleh Dairy Company as one the most prestigious companies in Iran would be like placed as one of pioneers in this framework and structure.

5.2. *Implementation*

In view of the fact that selecting the best supplier along with its performance evaluation is actually an intricate multi-criteria problem, so it is not appropriate to presume the elements supplier evaluation system as independent. As, all of the eight identified CRs are deemed to be vital, hence, it becomes indispensable to find the most important requirement of the evaluation system and measure the relationships among them. In order to achieve this, DEMATEL is used for envisaging the insightful relationships between the CRs causally and visually. Following the DEMATEL steps as described in Appendix, the relationships among different CRs are achieved using the integer scale as explained earlier. After the interrelationships are measured, the initial direct-relation matrix (A) is produced, as shown in Table 2. The matrix A is an 8×8 matrix, obtained by pair-wise comparisons in terms of influences and directions between the CRs.

From matrix A of Table 2, the normalized direct-relation matrix (X) is estimated as given in Table 3. Then, total-influence matrix (T) is derived as shown in Table 4. Now, the sums of rows and columns as represented by vectors D and R respectively are computed and are shown in Table 5. The causal diagram, as exhibited by Fig. 4, is obtained by plotting the dataset of Table 6. The ($D+R$) and (D-R) values of Table 6 represent the degree of total influence levels (central roles) and the degree of net influence levels respectively, where the positive values indicate that it will influence other requirements more than any other requirement influences it. Table 6 indicates that MC requirement has the largest net influence level, followed by FS.

Now, looking at the causal diagram of Fig. 2, it is apparent that CRs are visually segregated into the cause and effect groups. The cause group compiles of FS, MC, QCS and F, while the effect group composes EMS, WDP, M and RL. It is convincingly evident that FS, MC, QCS and F requirements are the main driving factors for EMS, WDP, M and RL. Among these eight CRs, MC is recognized as the most significant one because it has the maximum intensity of relation to others for having maximum $D+R$ value followed by FS. Furthermore, MC is also the most persuading factor due to its highest D-R value. Thus, MC plays a major role in the supplier evaluation problem, and it has the utmost effect on the others. On the converse, EMS is very much influenced by the other requirements, having the lowest (D-R) value. The threshold value (α) is derived from the mean of elements in matrix T, which is calculated using Eq. (7). The obtained α value is 0.0175. The values of t_{ij} in Table 4 which are greater than α value (0.0175), are shown as t_{ij}^* representing the interaction between two CRs, e.g. the value of t_{12} (0.0324) > α (0.0175), the arrow in the diagraph, as shown in Fig. 3, is drawn from FS to EMS. This digraph reveals contextual relationships among the components of the system.

The weights of the CRs are calculated by normalizing the values of prominence vector ($D+R$) of Table 6 and are shown in Table 7. From these values, it is observed that as MC is the most influencing factor and it has the highest weight among other CRs. Following the process of QFD (Appendix B), a central relationship matrix is constructed which exhibits the effects and relations between each pair of CR and corresponding supplier selection criteria. This task is handled by decision team based on their knowledge on suppliers which is exhibited in Table 8. Actually this step responds to the question of how CR and supplier evaluation criteria interact and influence through the values given by the experts. As seen in Table 8, the values are assigned to the matrix which show how supplier selection criteria can satisfy each CR.

Having central relationship matrix and weights of CRs, the weights of each supplier selection criteria is computed. The

Table 5
Computation of vectors D and R.

CR	D_k	R_k
FS	0.1636	0.1410
EMS	0.0890	0.2070
WDP	0.0861	0.1731
MC	0.2932	0.0228
QCS	0.1508	0.1405
M	0.1090	0.1843
F	0.1295	0.1079
RL	0.0966	0.1414

Table 6
Total and net effects for each green CR.

CR	$D+R$	D-R	Group
FS	0.3046	0.0226	Cause
EMS	0.2961	−0.1180	Effect
WDP	0.2592	−0.0869	Effect
MC	0.3160	0.2704	Cause
QCS	0.2913	0.0104	Cause
M	0.2934	−0.0753	Effect
F	0.2374	0.0216	Cause
RL	0.2380	−0.0448	Effect

Table 2
The initial direct-relation matrix (A).

CR	FS	EMS	WDP	MC	QCS	M	F	RL
FS	0	2	2	1	2	3	3	2
EMS	1	0	1	1	1	2	2	0
WDP	0	3	0	0	2	1	0	2
MC	4	4	4	0	4	4	4	3
QCS	3	3	3	0	0	3	0	2
M	3	2	1	0	1	0	1	2
F	1	2	2	0	2	3	0	2
RL	1	3	3	0	1	1	0	0

Table 3
Normalized direct-relation matrix (X) of green CRs.

CR	FS	EMS	WDP	MC	QCS	M	F	RL
FS	0	0.0194	0.0194	0.0097	0.0194	0.0291	0.0291	0.0194
EMS	0.0097	0	0.0097	0.0097	0.0097	0.0194	0.0194	0
WDP	0	0.0291	0	0	0.0194	0.0097	0	0.0194
MC	0.0388	0.0388	0.0388	0	0.0388	0.0388	0.0388	0.0291
QCS	0.0291	0.0291	0.0291	0	0	0.0291	0	0.0194
M	0.0291	0.0194	0.0097	0	0.0097	0	0.0097	0.0194
F	0.0097	0.0194	0.0194	0	0.0194	0.0291	0	0.0194
RL	0.0097	0.0291	0.0291	0	0.0097	0.0097	0	0

Table 4
Total-relation matrix (T) of green CRs ($t_{ij}^* > 0.0175$).

CR	FS	EMS	WDP	MC	QCS	M	F	RL
FS	0.0029	0.0324*	0.0226*	0.0103	0.0218*	0.0323*	0.0306*	0.0313*
EMS	0.0113	0.0018	0.0113	0.0100	0.0112	0.0212*	0.0204*	0.0017
WDP	0.0014	0.0306*	0.0016	0.0003	0.0201*	0.0112	0.0008	0.0201*
MC	0.0426*	0.0445*	0.0436*	0.0012	0.0425*	0.0442*	0.0414*	0.0333*
QCS	0.0307*	0.0322*	0.0311*	0.0006	0.0021	0.0313*	0.0018	0.0216*
M	0.0301*	0.0216*	0.0117	0.0006	0.0112	0.0023	0.0111	0.0209*
F	0.0118	0.0029	0.0213*	0.0099	0.0209*	0.0309*	0.0011	0.0118
RL	0.0107	0.0309*	0.0301*	0.0004	0.0110	0.0113	0.0010	0.0014

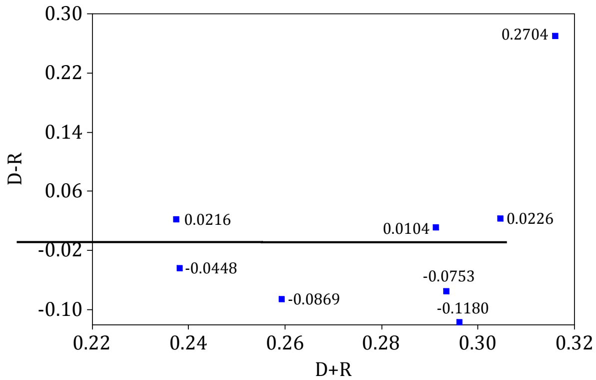

Fig. 2. DEMATEL causal diagram of green CRs.

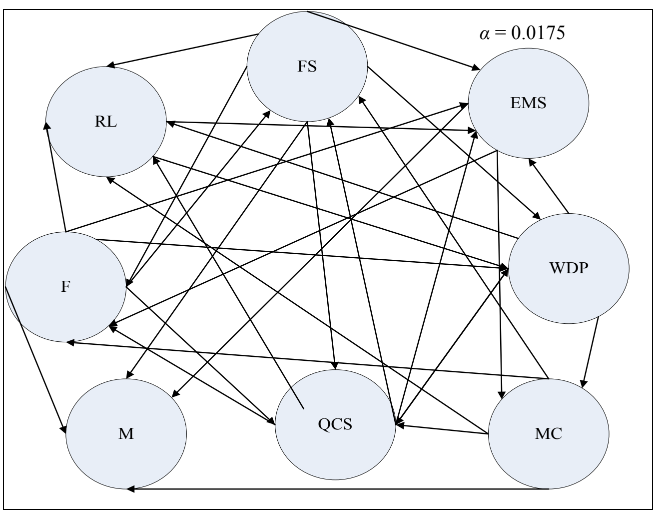

Fig. 3. DEMATEL diagraph for green supplier selection problem.

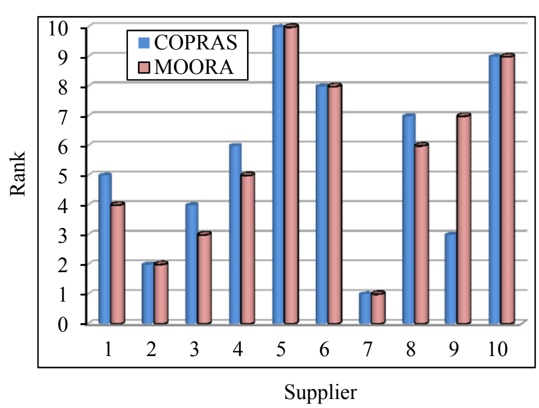

Fig. 4. Comparative ranking of suppliers.

normalized weights of all criteria are obtained which are shown in Table 8. From this table, it becomes clear that re-use and re-cycle rate (RRR) is the most important supplier evaluation criterion among others.

With respect to each evaluation criterion, suppliers are now rated using pairwise comparisons as stated before. It means seven pairwise comparisons are done for ten alternative suppliers. For

Table 7
Weights of green CRs.

CR	FS	EMS	WDP	MC	QCS	M	F	RL
Weight	0.1362	0.1324	0.1159	0.1413	0.1303	0.1312	0.1062	0.1064

instance, Tables 9 and 10 show the pairwise comparison matrices for alternative suppliers regarding ENRC and GD criteria respectively. For rest of the criteria, the same procedure is followed. At the end of this step, performance ratings of alternative suppliers and criteria weights are integrated to compose the initial decision matrix, as shown in Table 11.

For the purpose of performance evaluation of the ten alternative suppliers, COPRAS and MOORA methods are now applied respectively. At first, this supplier selection problem is solved using COPRAS method and thereafter MOORA method is applied.

For the application of COPRAS method, the initial decision matrix, as shown in Table 11, is the normalized matrix and the corresponding weighted normalized decision matrix, is given in Table 12. The normalization process is done to establish same scale for all criteria for the purpose of comparability. Now using Equations (12) and (13), the sums of the weighted normalized values are calculated for both the beneficial attributes (P_j) and non-beneficial attributes (R_j), as given in Table 13. Then, applying Eq. (14), the relative significance or priority value (Q_j) for each alternative supplier is determined, as shown in Table 13. This table also exhibits the value of quantitative utility (N_j) for each alternative on the basis of which the complete ranking of the alternative suppliers is obtained. The candidate suppliers are then arranged in descending order of N_j values. The best choice of supplier for the Iranian dairy company is S_7. S_2 is the second choice and the last choice is supplier S_5.

Now, the same supplier selection problem is solved using MOORA method. Table 14 shows the normalized performance scores of the alternatives with respect to the considered criteria, as obtained using Eq. (16). Then applying Eq. (17), the weighted normalized values are computed, as shown in Table 15. This table also exhibits the overall rating of benefit ($S^{+}{}_{j}$) and cost criteria ($S^{-}{}_{j}$) for all the alternative suppliers, determined employing Eqs. (18) and (19) respectively. Finally, the overall performance index (S_j) is calculated using Eq. (20) and a comparative ranking of the alternative suppliers is obtained as $S_7 > S_2 > S_3 > S_1 > S_4 > S_8 > S_9 > S_6 > S_{10} > S_5$ when the S_j values are arranged in descending order. It is observed that similar to COPRAS method, suppliers S_7 and S_2 emerge out as the first and second choices respectively. Also, COPRAS and MOORA methods confirm that S_{10} and S_5 are the worst suppliers. Moreover, to compare the ranking performances of the two MCDM methods, Spearman correlation coefficient (Chatterjee et al., 2014) is computed as 0.88 which reflects a strong agreement between the rankings provided by the two methods. MOORA method is a tool which is recognized as the process of simultaneously optimizing two or more conflicting criteria subjected to certain constraints, while COPRAS method ranks alternatives based on utility degree and their significances. Fig. 4 shows the comparative ranking preorder of the alternative suppliers.

From the initial decision matrix of Table 11, it is observed that supplier S_7 and S_2 outperforms most of the other alternative suppliers with respect to higher values of QD and RRR, and lower value of ENRC criteria. On the other hand, the main reason behind the underperformance of S_5 supplier is its very low RRR value, although it has amazingly attractive values for QD and DS criteria. It is identified that this supplier has very less capability in terms of energy and natural resource consumption (ENRC), delivery speed (DS), green design (GD), re-use and recycle rate (RRR) and

Table 8
QFD model for green supplier selection problem.

HOWs (CRs)	WHATs (Criteria)							Weight of CR
	QD	P	ENRC	DS	GD	RRR	PP	
FS		6			3			0.1362
EMS	3		3			3		0.1324
WDP						3		0.1159
MC	3	3	3		3	1		0.1413
QCS	3			6		1	3	0.1303
M			1	3		3	3	0.1312
F			3	3			3	0.1062
RL						6		0.1064
	1.2120	1.2410	1.2710	1.4940	0.8330	2.0490	1.1030	9.2020
Normalized criteria weight	0.1320	0.1350	0.1380	0.1620	0.0900	0.2230	0.1200	

Table 9
Pairwise comparison of green suppliers for ENRC criterion.

ENRC	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	Weights
S_1	1	6	3	3	4	0.11	0.33	1	5	7	0.15
S_2	0.167	1	0.25	7	0.5	9	1	2	3	4	0.108
S_3	0.333	4	1	4	6	2	1	4	4	0.13	0.128
S_4	0.333	0.143	0.25	1	0.14	6	3	0.17	3	1	0.058
S_5	0.25	2	0.167	7	1	0.2	4	8	2	3	0.125
S_6	9	0.111	0.5	0.167	5	1	6	0.17	8	0.25	0.15
S_7	3	1	1	0.333	0.25	0.167	1	2	1	0.333	0.056
S_8	1	0.5	0.25	6	0.125	6	0.5	1	6	2	0.086
S_9	0.2	0.333	0.25	0.333	0.5	0.125	1	0.167	1	6	0.043
S_{10}	0.143	0.25	8	1	0.333	4	3	0.5	0.167	1	0.097

Table 10
Pairwise comparison of green suppliers for GD criterion.

GD	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	Weights
S_1	1	2	1	7	4	3	0.5	2	1	3	0.156
S_2	0.5	1	4	0.2	1	0.143	2	0.333	5	2	0.082
S_3	1	0.25	1	1	0.5	0.25	5	3	3	7	0.108
S_4	0.143	5	1	1	3	5	6	2	2	1	0.132
S_5	0.25	1	2	0.33	1	0.333	5	4	0.25	0.333	0.074
S_6	0.333	7	4	0.2	3	1	7	0.5	4	0.25	0.134
S_7	2	0.5	0.2	0.167	0.2	0.143	1	5	6	9	0.122
S_8	0.5	3	0.333	0.5	0.25	2	0.2	1	3	1	0.062
S_9	1	0.2	0.333	0.5	4	0.25	0.167	0.333	1	0.25	0.05
S_{10}	0.333	0.5	0.143	1	3	4	0.111	1	4	1	0.08

Table 11
Initial decision matrix for supplier evaluation.

Weight	0.132	0.135	0.138	0.162	0.090	0.223	0.120
Supplier	QD	P	ENRC	DS	GD	RRR	PP
S_1	0.068	0.066	0.150	0.098	0.156	0.114	0.098
S_2	0.078	0.076	0.108	0.136	0.082	0.171	0.105
S_3	0.157	0.114	0.128	0.083	0.108	0.113	0.131
S_4	0.106	0.139	0.058	0.074	0.132	0.084	0.120
S_5	0.103	0.187	0.125	0.176	0.074	0.064	0.057
S_6	0.105	0.083	0.150	0.051	0.134	0.094	0.113
S_7	0.137	0.127	0.056	0.133	0.122	0.119	0.114
S_8	0.100	0.082	0.086	0.060	0.062	0.109	0.093
S_9	0.053	0.052	0.043	0.100	0.050	0.078	0.063
S_{10}	0.094	0.074	0.097	0.087	0.080	0.054	0.106

Table 12
Weighted normalized matrix for COPRAS method.

Supplier	QD	P	ENRC	DS	GD	RRR	PP
S_1	0.0089	0.0089	0.0207	0.0159	0.0141	0.0253	0.0118
S_2	0.0103	0.0103	0.0149	0.0221	0.0075	0.0382	0.0126
S_3	0.0206	0.0154	0.0176	0.0136	0.0097	0.0251	0.0157
S_4	0.0140	0.0188	0.0081	0.0120	0.0119	0.0187	0.0144
S_5	0.0135	0.0252	0.0173	0.0286	0.0067	0.0143	0.0068
S_6	0.0138	0.0112	0.0207	0.0083	0.0121	0.0210	0.0135
S_7	0.0180	0.0171	0.0077	0.0217	0.0110	0.0266	0.0137
S_8	0.0132	0.0110	0.0119	0.0098	0.0056	0.0242	0.0111
S_9	0.0070	0.0070	0.0059	0.0162	0.0045	0.0173	0.0075
S_{10}	0.0124	0.0100	0.0134	0.0142	0.0072	0.0120	0.0127

production planning (PP).

A graphical view of the Pareto analysis results based on Q_j and S_j values of the ten alternative suppliers is presented in Fig. 5 (a) and (b) respectively for COPRAS and MOORA methods. From Fig. 5 (a) and (b), it is observed that suppliers S_7 and S_2 (with a cumulative Q_j or S_j of 80–100%) can be considered as the benchmarks for suppliersS_9, S_3, S_1, S_4, S_8 and S_6, (which form the second group with a cumulative Q_j or S_j of 20–80%) and this second group can be adjudged as an improvement target for suppliers S_{10} and S_5 (cumulative Q_j or S_j of 0–20%).

5.3. Managerial tips

The outcomes of this study are headlines for the Kalleh dairy company to enhance the quality and deliver fitted product based on

Table 13
P_j, R_j, Qj and Nj values in COPRAS method.

Supplier	P_j	R_j	Q_j	N_j	Rank
S_1	0.0761	0.0295	0.0992	84	5
S_2	0.0906	0.0252	0.1177	99	2
S_3	0.0847	0.033	0.1054	89	4
S_4	0.071	0.0269	0.0964	81	6
S_5	0.0699	0.0425	0.086	73	10
S_6	0.0687	0.0318	0.0901	76	8
S_7	0.091	0.0248	0.1184	100	1
S_8	0.064	0.023	0.0937	79	7
S_9	0.0525	0.0129	0.1055	89	3
S_{10}	0.0585	0.0234	0.0877	74	9

Table 14
Normalized decision matrix for MOORA method.

Supplier	QD	P	ENRC	DS	GD	RRR	PP
S_1	0.206	0.1943	0.4437	0.291	0.469	0.343	0.3036
S_2	0.2364	0.2249	0.3197	0.4048	0.2472	0.5167	0.3239
S_3	0.4759	0.3357	0.3788	0.248	0.3228	0.3396	0.4048
S_4	0.3225	0.4108	0.1733	0.2204	0.3948	0.2529	0.3698
S_5	0.3114	0.5496	0.3724	0.5235	0.2225	0.1933	0.1756
S_6	0.3192	0.2441	0.4439	0.1522	0.4009	0.2839	0.3475
S_7	0.4146	0.3736	0.1655	0.3963	0.3661	0.3597	0.3526
S_8	0.3042	0.2411	0.2562	0.1786	0.1867	0.3281	0.2867
S_9	0.1607	0.1531	0.1262	0.2966	0.1503	0.2338	0.194
S_{10}	0.2863	0.2179	0.2877	0.2595	0.2393	0.1625	0.3263

green regulations to finally reward consumers. Moreover, the top-ranked suppliers' evaluation scores can be outlined for the rest of suppliers to comprehend their weaknesses and fulfill logical pattern for future plans. We have tried to develop a basis for generous relation of company with its partners to reduce their weaknesses. The findings of this study are argued and confirmed to the Kalleh and POLE executives. The ability to model the supplier's performance over a set of criteria will offer Kalleh to launch a capability building anatomy for productive management competencies.

We believe that the proposed model is sufficient robust and could be easily implemented in practices for multi-criteria decision-making problems. Managers can more effectively form their decision structure and detect the relative importance of their supplier attributes. The released model tries to aid managers to prioritize their supplier's development programs focusing on customer and external parameters delivering effective performance among suppliers. Evaluating the supplier performance effectively improves performance and behavior of suppliers regarding weak attribute and also allocate more credit to the stronger suppliers to appreciate all practices to the next level. Although, many researches previously investigated many techniques to undertake the supplier selection problem, mostly are challenging to implement in real life.

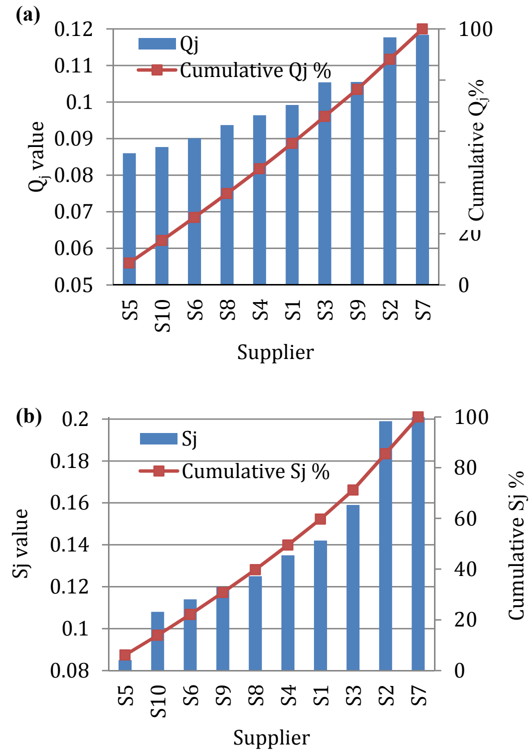

Fig. 5. **(a)** Pareto analysis of Q_j values for ten alternative suppliers. **(b)** Pareto analysis of S_j values for ten alternative suppliers.

Current work points out an integrated approach to address the real life supplier selection problem involving customer opinions and request to the core activities of suppliers.

6. Conclusions

With the revolutionizing change in the state of environment, subsequent public pressure and environmental logistics, environmental and social issues are becoming more important in managing any business. GSCM is an approach to advance the performance of the process and products in accordance with the environmental requirements and regulations. GSCM envelops all phases of product's life cycle from design, production and distribution and whole supply chain to the use of products by the end users and its disposal at the end of product's life cycle. Role of suppliers cannot be ignored.

In view of this, the supplier selection criteria have to be redesigned according to green perspective. Hence, the main objective of

Table 15
Weighted normalized matrix and ranking of supplier using MOORA method.

Supplier	QD	P	ENRC	DS	GD	RRR	PP	S^+_j	S^-_j	S_j	Rank
S_1	0.027	0.026	0.061	0.047	0.042	0.076	0.036	0.230	0.087	0.142	4
S_2	0.031	0.030	0.044	0.066	0.022	0.115	0.039	0.273	0.074	0.199	2
S_3	0.063	0.045	0.052	0.040	0.029	0.076	0.049	0.256	0.098	0.159	3
S_4	0.042	0.055	0.024	0.036	0.036	0.056	0.044	0.215	0.079	0.135	5
S_5	0.041	0.074	0.051	0.085	0.020	0.043	0.021	0.210	0.126	0.085	10
S_6	0.042	0.033	0.061	0.025	0.036	0.063	0.042	0.208	0.094	0.114	8
S_7	0.055	0.050	0.023	0.064	0.033	0.080	0.042	0.274	0.073	0.201	1
S_8	0.040	0.033	0.035	0.029	0.017	0.073	0.034	0.193	0.068	0.125	6
S_9	0.021	0.021	0.017	0.048	0.014	0.052	0.023	0.158	0.038	0.120	7
S_{10}	0.038	0.029	0.040	0.042	0.022	0.036	0.039	0.177	0.069	0.108	9

this paper is set to resolve the issue of evaluating and ranking green suppliers utilizing an integrated formulation. This paper evaluates and elucidates the interaction relationships and impact levels between the CRs and supplier selection criteria and also to determine the weights of the CRs and supplier selection criteria respectively. DEMATEL facilitates to build up the underlying relationship diagram, dividing the considered CRs into cause and effect groups.

Based on the results, it is recommended that the organization should focus on maintaining product and process quality, energy and natural resource consumption, green design with increased re-use and recycle rate according to different environmental regulations. It is figured out strong management commitment is the key driving force for sustainable developments in infrastructure, facility and quality. It is also the responsibility of the management to strongly focus on improved manufacturing and reverse logistics processes and production planning activities for maintaining an efficient GSCM system.

The findings of this paper put forward some important insights on different attributes which considerably contribute to supplier performance and efficiencies so that inefficient suppliers can focus on those attributes to improve their performances. From the Pareto analysis, it is observed that the inefficient suppliers have to increase their re-use and recycle rate, condense energy and natural resource consumption and increase delivery performance and should adopt the benchmark policies and techniques of the Pareto efficient suppliers with respect green design aspects, price, quality adaptation principles, suitable waste disposal program and appropriate production planning. It is expected that the proposed integrated framework will serve as a vital tool in devising environmentally conscious SCM system which will enable organizations to become more competitive, while achieving sustainable development.

The proposed supplier selection approach enables the DMs to better understand the complex relationships of the relevant attributes in the decision-making process which may subsequently improve the reliability of the decision and also contributes in promoting sustainable development to some extent. The methodology can easily be adjusted to solve other decision-making problems involving any number of alternatives and any number of criteria.

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APPENDIX

A) DEMATEL method

The application of DEMATEL method consists of the following seven steps (Tamura and Akazawa, 2005; Tzeng et al., 2007; Ranjan et al., 2014). It presumes a system restraining a set of components $C = \{C_1, C_2, \ldots, C_n\}$, with pair-wise relations that can be assessed.

Step 1: Generation of the direct-relation matrix (A) by scores:

At first, the DM indicates the relationship between the sets of paired criteria that signifies the direct effect that each ith criterion exerts on each jth criterion, as specified by an integer score ranging from 0 to 4, representing no influence (0), low influence (1), medium influence (2), high influence (3) and very high influence (4). As a result of these assessments, a direct-relation matrix (A) is obtained in the form of an $n \times n$ matrix, in which the individual element (a_{ij}) denotes the degree to which ith criterion affects jth criterion and n denotes the total number of criteria.

$$A = \begin{bmatrix} 0 & a_{12} & \ldots & a_{1j} & \ldots & a_{1n} \\ a_{21} & 0 & \ldots & a_{2j} & \ldots & a_{2n} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ a_{n1} & a_{n2} & \ldots & a_{nj} & \ldots & 0 \end{bmatrix} \quad (1)$$

Step 2: Formation of the normalized direct-relation matrix (X):

After the generation of the direct-relation matrix (A), the normalized matrix (X) is achieved using Eq. (2). Each element in matrix X ranges from 0 to 1.

$$X = k \cdot A \quad (2)$$

where

$$k = \frac{1}{\max\limits_{1 \le i \le n}\left(\sum_{j=1}^{n} a_{ij}\right)}, i,j = 1,2,\ldots,n \quad (3)$$

Step 3: Computation of the total-relation matrix (T):

The total-relation matrix (T) is obtained by Eq. (4), in which I denotes the identity matrix. Each element (t_{ij}) of this matrix symbolizes the indirect influences that ith criterion imparts on jth criterion, and the matrix T reveals the total relationship between each pair of decision variables.

$$T = [t_{ij}]_{n \times n}, i,j = 1,2,\ldots,n$$

$$\begin{aligned} T &= X + X^2 + X^3 + \ldots + X^k \\ &= X\left(I + X + X^2 + \ldots + X^{k-1}\right)\left[(I - X)(I - X)^{-1}\right] \\ &= X\left(I - X^k\right)(I - X)^{-1} \text{ Then,} \end{aligned}$$

$$T = X(I - X)^{-1}\mathrm{T}, \text{ when } k \to \infty, X^k = [0]_{n \times n}$$

$$T = X(I - X)^{-1} \quad (4)$$

Step 4: Determination of the sums of rows and columns of matrix T:

In the total-relation matrix T, the sum of rows and sum of columns are represented by vectors D and R, as derived using Eqs. (5) and (6) respectively.

$$D_i = \left[\sum_{j=1}^{n} t_{ij}\right]_{n \times 1} = [t_i]_{n \times 1}, i = 1,2,\ldots,n \quad (5)$$

$$R_j = \left[\sum_{i=1}^{n} t_{ij}\right]_{1 \times n} = [t_j]_{n \times 1}, j = 1,2,\ldots,n \quad (6)$$

Step 5: Setting a threshold value (α):

Since matrix T provides information on how one factor affects another, it thus becomes essential for the DM to set a threshold value (α) for elucidating the structural relation among criteria while simultaneously keeping the intricacy of the entire system to a convenient level. This threshold value is generally determined by experts in order to set up the minimum value of influence level. An influence relationship between two elements is excluded from the map if their correlation value in matrix T is smaller than α and only the effects greater than the set α value are chosen and shown in the digraph. In this paper, the value of α is computed from the average of the elements in matrix T, as computed using Eq. (7), where N is the total number of elements in matrix T.

$$\alpha = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} [t_{ij}]}{N} \quad (7)$$

Step 6: Development of a causal diagram:

The causal diagram is a classification of the degree of each criterion. It shows the criterion which be easily classed as either a passive one or active one. The horizontal axis vector ($D_k + R_k$) named 'prominence' is computed by adding D to R while $k = i = j = 1$ which reveals how much importance the criterion has. Similarly, the vertical axis (D_k-R_k) named 'relation' is calculated by subtracting D from R, which divides the criteria into a cause group and an effect group. The "prominence axis" of the causal diagram indicates the criterion which affects others and be affected by others. The "relation axis" can divide the criteria into the causal and effect groups. Generally, when the value of "relation" is positive, the criterion belongs to the causal group and if the value is negative, the criterion belongs to the effect group. Hence, causal diagrams can visualize the complicated causal relationships and interaction influence levels between the criteria into a visible structural model, providing valuable insights for problem solving. Further, with the help of the causal diagram, the DM can find the driving variables of the core problem in a complicated system, and plan for suitable decisions to solve the problem in accordance with attribute type and influence level.

Step 7: Calculation of criteria weights:

The criteria weights (C_i) are calculated by normalizing the prominence vector ($D_k + R_k$) in which the sum of normalized weights equals to 1.

B) QFD model

In a general QFD model, the following items are incorporated in the HoQ, as shown in Fig. 6.

- A: WHATs matrix
- B: HOWs matrix
- C: relationship matrix between WHATs and HOWs
- D: relative importance or weights of WHATs
- E: interrelationship between HOWs
- F: weights of HOWs

The general steps of QFD model implementation are as follows:

Step 1: Identify the WHATs.

Step 2: Identify HOWs. TRs are specified as the HOWs in the HoQ and positioned on the area marked as 'B' of Fig. 6.

Step 3: Development of HOWs matrix (E) indicating inner dependence among the HOWs.

Step 4: Priority weights are assigned to the CRs. For assigning the priority value to the CRs, a 5 point scale representing not important (1), important (2), much more important (3), very important (4) and most important (5) is set.

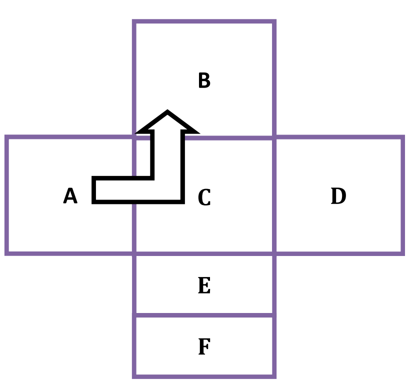

Fig. 6. General QFD model.

Step 5: Development of the relationship matrix (C) or the HoQ by judging the degree of impact between HOWs and WHATs expressing how much each HOW affects each WHAT using an appropriate scale (here, a four point scale as 1, 3, 6, and 9 addressing weak, moderate, strong and very strong relationships has been used).

Step 6: Once the HoQ matrix is developed, compute the overall priorities of TRs signifying the synthesized importance of the TRs or HOWs.

In QFD, the output of each phase (HOWs) is transformed into the inputs of the next phase (new WHATs). Advantages of applying QFD can be counted as; higher customer satisfaction, shorter lead time, better flexibility, quality promotion, reduction of time to market, and knowledge preservation (Khademi-Zare et al., 2010; Ignatius et al., 2016).

C) COPRAS method

The computational steps as involved in COPRAS method-based analysis are now presented below (Zavadskas et al., 1994):

Step 1: Let D is a decision matrix, containing the performance rating of m number of alternatives with respect to n number of criteria, as shown below.

$$D = \begin{bmatrix} x_{11} & x_{12} & .... & x_{1n} \\ x_{21} & x_{22} & ..... & x_{2n} \\ .... & ... & ... & ... \\ x_{m1} & x_{m2} & .... & x_{mn} \end{bmatrix} \quad (8)$$

wherex_{ij} is the rating of i^{th} decision criteria on j^{th} alternative, whereas, m is the number of alternatives and n is the number of criteria.

Step 2: Normalize the decision matrix using Eq. (9).

$$r_{ij} = \frac{x_{ij}}{\sum_{j=1}^{m} x_{ij}}, \quad j = 1, 2, ..., m \quad i = 1, 2, ..., n \quad (9)$$

Step 3: Calculate the weighted normalized decision matrix as follows: where w_i includes the weights of criteria and given by $\sum_{i=1}^{n} w_i = 1$;

$$v_{ij} = w_i \times r_{ij} \quad , j = 1, 2, ..., m \quad i = 1, 2, ..., n \quad (10)$$

The sum of dimensionless weighted normalized values of each criterion is always equal to the weight for that criterion.

$$\sum_{j=1}^{m} v_{ij} = w_i \quad (11)$$

Thus, it can be said that the weight, w_i of ith criterion is proportionally distributed among all the alternatives according to their weighted normalized value v_{ij}.

Step 4: Calculate the sums of weighted normalized values for both the beneficial (P_j) and non-beneficial attributes(R_j) using the following equations:

$$P_j = \sum_{i=1}^{k} v_{ij} \quad (12)$$

where$k$ is the number of criteria to be maximized.

$$R_j = \sum_{i=1}^{n-k} v_{ij} \tag{13}$$

Where $(n-k)$ is the number of criteria to be minimized.

Step 5: Determine the relative significances or priorities of the alternatives as follows:

$$Q_j = P_j + \frac{\sum_{j=1}^{m} R_j}{R_j \sum_{j=1}^{m} \frac{1}{R_j}}, \tag{14}$$

Step 6: Calculate the quantitative utility (N_j) for jth alternative. The degree of an alternative's utility which leads to a complete ranking of the candidate alternatives is determined by comparing the priorities of all the alternatives with the most efficient one and can be denoted as below:

$$N_j = \frac{Q_j}{Q_{\max}} \times 100\% \tag{15}$$

whereQ_{max} is the maximum relative significance value. These utility values of the alternatives range from 0% to 100%. Thus, this approach allows for evaluating the direct and proportional dependence of significance and utility degree of the considered alternatives in a decision-making problem having multiple criteria, their weights and performance values of the alternatives with respect to all the criteria.

D) MOORA method

The step by step application procedure of MOORA (Brauers and Zavadskas, 2006) method is explained below:

Step 1: To have a dimensionless and comparable element in the evaluation process, the ratio system of MOORA method first computes the normalized decision matrix, as shown below:

$$r_{ij} = \frac{x_{ij}}{\sum_{j=1}^{m} x_{ij}^2} \tag{16}$$

Step 2: Determine the weighted normalized matrix as:

$$v_{ij} = w_i \times r_{ij} \tag{17}$$

Step 3: Compute the overall rating of benefit and cost criteria for all alternatives implementing the following equations:

$$S_j^+ = \sum_{i=1}^{n} v_{ij}, \;\; i \in J^{Max} \tag{18}$$

where J^{Max} is related to the beneficial criteria where higher values are desirable.

For non-beneficial criteria, Eq. (19) is changed to:

$$S_j^- = \sum_{i=1}^{n} v_{ij}, \;\; i \in J^{Min} \tag{19}$$

where J^{Min} is related to the non-beneficial criteria for which lower values are preferable.

Step 4: Obtain the overall performance index by mutually subtracting the overall ratings for beneficial and cost criteria using the following formula:

$$S_j = S_j^+ - S_j^- \tag{20}$$

The S_j values indicate cardinal scales which can be compared in form of an ordinal ranking of the alternatives.

Step 5: The ranking for each alternative is obtained by arranging the S_j values in descending order. It means higher values of S_j exhibit better priority order and would be preferred.

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