Int. J. Production Economics 159 (2015) 178–191

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

An integrated green supplier selection approach with analytic network process and improved Grey relational analysis

Seyed Hamid Hashemi [a], Amir Karimi [b], Madjid Tavana [c,d,*]

[a] Department of Industrial Management, Faculty of Management, University of Tehran, Tehran, Iran
[b] Carlson School of Management, University of Minnesota, Minneapolis, MN 55455, USA
[c] Business Systems and Analytics Department, Lindback Distinguished Chair of Information Systems and Decision Sciences, La Salle University, Philadelphia, PA 19141, USA
[d] Business Information Systems Department, Faculty of Business Administration and Economics, University of Paderborn, D-33098 Paderborn, Germany

ARTICLE INFO

Article history:
Received 12 September 2013
Accepted 17 September 2014
Available online 28 September 2014

Keywords:
Green supply chain management (GSCM)
Environmental sustainability
Supplier selection
Analytic network process (ANP)
Improved Grey relational analysis (GRA)
Grey theory

ABSTRACT

With increased worldwide awareness of environmental protection, green supply chain management (GSCM) has received much attention from both researchers and practitioners over the past decade. Traditionally, organizations have considered criteria such as cost, quality, and delivery to evaluate the performance of their suppliers. Although there is an abundance of studies considering the conventional criteria in supplier selection, there are a rather limited number taking into account the environmental issues. In this study, we use both economic and environmental criteria and propose a comprehensive green supplier selection model. The analytic network process (ANP) is used to deal with the interdependencies among the criteria, and the traditional Grey relational analysis (GRA) has been modified to better address the uncertainties inherent in supplier selection decisions. We utilize the ANP and an improved GRA to weight the criteria and rank the suppliers respectively. The proposed approach is novel, and allows decision-makers to participate in the assessment process and use linguistic evaluation in the green supplier selection process. A case study in the automotive industry is presented to demonstrate the effectiveness of the proposed approach.

1. Introduction

The subject of green supply chain management (GSCM) has attracted increasing attention from both researchers and practitioners because of the growing concerns with regards to the detrimental impacts of businesses operations on the environment. This growing interest is fueled by the intensifying deterioration of the environment, increasing levels of pollution, overflowing waste sites, and diminishing raw material resources (Srivastava, 2007). Additionally, increasing government regulation, stronger public awareness, and consumer pressures are making businesses more cautious regarding the environmental impacts of their operations (Diabat et al., 2013; Lee et al., 2009; Srivastava, 2007). As organizational stakeholders including governments, customers, employees, competitors and communities place more emphasis on protecting the environment, environmental management is becoming increasingly important (Sarkis, 1998). Today, businesses cannot simply neglect environmental issues if they intend to survive in the global market (Lee et al., 2009).

Within supply chain management, supplier selection decisions are generally considered to be one of the most significant responsibilities of managers (Golmohammadi and Mellat-Parast, 2012), and at the same time one of the most critical and complex issues they need to deal with (Bai and Sarkis, 2010b). In order to maintain a competitive advantage in the global market, organizations need to take into account environmental concerns and embrace evaluation models of supplier selection. Supplier selection decisions can be applied in many situations such as the case of multiple suppliers as well as in the different stages of a product's life cycle from initial raw material purchasing to end-of-life service providers (Bai and Sarkis, 2010b).

Current supply chain management tends to maintain long-term relationships with suppliers, and use fewer but more reliable suppliers (Ho et al., 2010). However, with increased awareness of environmental issues, managers today need to purchase from suppliers that can provide them goods and services with lower

* Corresponding author at: Business Systems and Analytics Department, Lindback Distinguished Chair of Information Systems and Decision Sciences, La Salle University, Philadelphia, PA 19141, USA. Tel.: +1 215 951 1129; fax: +1 267 295 2854.
E-mail addresses: s.hamidhashemi@ut.ac.ir (S.H. Hashemi), karim100@umn.edu (A. Karimi), tavana@lasalle.edu (M. Tavana).
URL: http://tavana.us/ (M. Tavana).

http://dx.doi.org/10.1016/j.ijpe.2014.09.027
0925-5273/

price, higher quality, shorter lead time, and at the same time with stronger focus on environmental responsibility (Lee et al., 2009). According to some researchers, supplier selection either in GSCM or sustainable supply chain management is considered to be very important in purchasing decisions (Hsu et al., 2013; Seuring and Müller, 2008).

While there are plenty of studies dedicated to supplier selection based on conventional criteria, the literature regarding green supplier evaluation or works that consider environmental criteria are rather limited (Handfield et al., 2002; Humphreys et al., 2003; Lee et al., 2009; Noci, 1997). Therefore, this study is aimed primarily at providing a comprehensive green supplier selection model by considering both economic and environmental criteria. We intend to develop a Grey-based green supplier selection model by integrating two techniques: the analytic network process (ANP) and an improved Grey relational analysis (GRA). Although we find several examples of GRA applications in the research literature, a number of drawbacks and limitations are associated with the current models such as the judgment bias of experts and not taking into account the interdependencies among criteria. As a result, the drawbacks of the existing models are discussed comprehensively and solutions are proposed. ANP is an extension of the analytic hierarchy process (AHP) and is capable of handling interdependencies among different criteria, thus being more realistic in certain situations where criteria are internally dependent. Moreover, since decision-making in supplier selection generally deals with uncertain information, such decisions become more difficult and complex. Grey theory is a decision-making approach under conditions of uncertainty, and has been found to be superior to comparable methods in the mathematical analysis of systems with incomplete information (Li et al., 2007). In this paper, we used ANP to calculate the criteria weights. In addition, the traditional GRA has been modified to address the interval problems and to better deal with the uncertainty in supplier selection decisions. A case study in the automotive industry is presented to demonstrate the effectiveness of the proposed approach in green supplier assessment and selection problems. Altogether, we contribute to both decision-making theory and practice by addressing limitations of the existing models, as well as implementing a comprehensive green supplier selection model in a case study of the automotive industry.

The remainder of the paper is organized as follows: Section 2 reviews the literature on GSCM, green supplier selection criteria and evaluation methods. Section 3 deals mainly with the research methods including ANP and improved GRA. Section 4 presents the green supplier selection approach proposed in this study. In Section 5, a case study of the automotive industry is presented. Section 6 deals with the results followed by a sensitivity analysis. Finally, in Section 7 we present our managerial implications and in Section 8 we present our conclusions and future research directions.

2. Literature review

2.1. Green supply chain management

GSCM has its roots in both the supply chain management and environmental management literature. The scope of GSCM in the literature has ranged from green purchasing to integrated green supply chains flowing from supplier to customer, and even reverse logistics (Srivastava, 2007; Zhu and Sarkis, 2004). GSCM is defined by Srivastava (2007) as "integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers, as well as end-of-life management of the product after its useful life". Sarkis (2006) defines GSCM in a relatively similar way and describes it as the integration of natural environmental factors into supply chain management. According to Green et al. (1996), "green supply refers to the way in which innovations in supply chain management and industrial purchasing may be considered in the context of the environment". In addition, Narasimhan and Carter (1998) argue that "environmental supply chain management consists of the purchasing function's involvement in activities that include reduction, recycling, reuse and the substitution of materials". From the viewpoint of Messelbeck and Whaley (1999), "the environmental effects of developing, manufacturing, storing, transporting, and using a product, as well as disposing of the product waste, must be considered" in GSCM.

Practices implemented to protect the environment might range from reactive monitoring of the environmental management programs to more proactive practices such as recycling, reclamation, remanufacturing, and reverse logistics (Zhu and Sarkis, 2004). Other examples of GSCM practices include developing the environmental life cycle analysis of products into supplier processes, encouraging implementation of environmental management systems into suppliers' organizational structure, incorporating supplier input into greening organizational practices, reducing packaging and waste, and many other similar initiatives (Sarkis, 2006). On the other hand, some organizations green their supply chains through evaluation and selection of appropriate green suppliers (Fu et al., 2012; Sarkis, 2006). The GSCM literature suggests encouraging existing suppliers to enhance their environmental performance by acquiring certifications or introducing green practices (Fu et al., 2012). While earlier studies in the literature have mainly focused on conventional criteria such as price, quality and delivery time, more recent research is moving towards the integration of environmental factors into supplier selection decisions (Baskaran et al., 2012).

2.2. Green supplier selection criteria

2.2.1. Economic criteria

In reviewing the literature, we see that several conventional criteria have been identified by scholars of supply chain management. In fact, the theoretical basis for the evaluation of suppliers started with transaction cost economics and a resource-based view of the organization. The main concept underlying the term 'transaction cost economics' is that an organization's primary concentration should be 'profit maximization'. As a result, the 'price' criterion has received more attention than other criteria such as quality or delivery (Baskaran et al., 2012). Several studies taking into account the conventional criteria have emphasized the price criterion as the main concern of industries (Gupta and Krishnan, 1999; Simpson et al., 2002). Ho et al. (2010) concluded in a literature review of supplier selection models that the most popular economic criteria among researchers are quality, delivery, cost, management, technology, and flexibility. They argue that the single criterion approach based on the lowest cost bidding is no longer relevant and significant in contemporary supply chain management. Table 1 presents a summary of the most important economic criteria in the research literature.

2.2.2. Environmental criteria

Among conventional studies of supplier selection, neither environmental nor social sustainability criteria have been emphasized (Bai and Sarkis, 2010b). With environmental awareness, increasingly more and more authors are addressing supplier selection in the light of environmental aspects (Handfield et al., 2002; Lee et al., 2009; Sarkis, 2006). However, although a firm

Table 1
Economic supplier selection criteria. (
Source: Amin and Zhang, 2012; Amindoust et al., 2012; Bai and Sarkis, 2010b; Chan, 2003b; Choi and Hartley, 1996; Golmohammadi and Mellat-Parast, 2012; Govindan et al., 2013; Gupta and Krishnan, 1999; Ho et al., 2010; Lee et al., 2009; Sarkis and Talluri, 2002; Simpson et al., 2002).

Criteria	Related attributes in the literature
Cost	Appropriateness of the materials price to the market price, competitiveness of cost, cost reduction capability, cost reduction performance, fluctuation on costs, direct cost, logistics cost, manufacturing cost, unit cost, ordering cost, inventory cost, warehouse cost, total cost of shipments, product price
Quality	Acceptable parts per million, compliance with quality, continuous improvement programs, corrective and preventive action system, documentation and self-audit, inspection and control, ISO quality system installed, shipment quality, quality award, quality certification, number of quality staff, rejection from customers
Delivery	Appropriateness of the delivery date, compliance with due date, delivery delays, delivery efficiency, delivery lead time, delivery reliability, number of shipments to arrive on time, waiting time
Technology	Current manufacturing facilities/capabilities, technological development of the supplier to meet current and future demand of the firm, capability of R&D and new product design of the supplier to meet current and future demand of the organization, technological compatibility, capacity, suppliers speed in development
Flexibility	Product volume changes, short set-up time, conflict resolution, service capability number of tasks performable by a worker, using flexible machines, the demand that can be profitably sustained, time or cost required to add new products to the existing production operation
Culture	Feeling of trust, management attitude for the future, strategic fit, top management capability, compatibility among levels and functions, suppliers organizational structure and personnel, future strategy direction, degree of strategic cooperation
Innovativeness	New launch of products, new launch of technologies
Relationship	Long-term relationship, relationship closeness, communication openness, reputation of integrity

Table 2
Environmental supplier selection criteria. (
Source: Amin and Zhang, 2012; Amindoust et al., 2012; Bai and Sarkis, 2010b; Govindan et al., 2013; Kuo et al., 2010; Lee et al., 2009; Shen et al., 2013; Zhu and Sarkis, 2004).

Criteria	Related attributes in the literature
Pollution production	Average volume of air pollutants, waste water, solid waste, and harmful materials released
Pollution control	Remediation, end-of-pipe controls
Resource consumption	Consumption of resources in terms of raw material, energy, and water
Eco-design	Design for resource efficiency, design of products for reuse, recycle, and recovery of material, design for reduction or elimination of hazardous materials
Environmental management system	Environmental certificates such as ISO 14000, continuous monitoring and regulatory compliance, environmental policies, green process planning, internal control process
Green image	Ratio of green customers to total customers, social responsibility
Green competencies	Materials used in the supplied components that reduce the impact on natural resources, ability to alter process and product for reducing the impact on natural resources
Green product	Use of recycled and nontoxic materials, green packaging, excess packaging reduction
Staff environmental training	Staff training on environmental issues
Management commitment	Commitment of senior managers to support and improve green supply chain management initiatives

needs to consider both environmental and conventional factors in order to select the most appropriate supplier for partnership, existing works have generally considered environmental aspects only (Kuo et al., 2010; Lee et al., 2009). Thus, this study intends to present a comprehensive green supplier selection framework by considering both economic and environmental criteria. As shown in Table 2, criteria such as pollution production, resource consumption, eco-design (*e*nvironmental-*co*nscious design), green image, and environmental management systems are the criteria most commonly referred to in the green supplier selection literature.

2.3. *Supplier evaluation methods*

Several decision-making approaches for supplier selection have been introduced in the past three to four decades, including AHP, ANP, the matrix method, artificial neural networks (ANN), case-based reasoning (CBR), data envelopment analysis (DEA), fuzzy set theory, the genetic algorithm (GA), mathematical programming (MP), the simple multi-attribute rating technique (SMART), GRA, and their hybrids. A detailed overview of supplier selection methods can be found in Chai et al. (2013), de Boer et al. (2001), and Ho et al. (2010).

Early studies of supplier assessment involved a formulation of mathematical modeling such as linear programing (LP), non-linear programing, or mixed integer programing. Some examples of the application of mathematical programming in supplier selection are the studies of Ghodsypour and O'Brien (1998) and Talluri (2002), making use of mixed integer non-linear programming and integer programming respectively. However, operational managers generally consider mathematical programming to be too complex for practical use. In addition, supplier selection decisions in reality usually involve both quantitative and qualitative criteria (Baskaran et al., 2012). In such cases, methods such as AHP (Saaty, 1980) are mostly preferred. AHP is capable of reflecting the natural preference of the human brain to sort components of a system into distinctive levels and group similar components in each level. A number of studies having applied AHP in supplier evaluation include Alinezad et al. (2013), Chan (2003a), Ghodsypour and O'Brien (1998), Handfield et al. (2002), Lee et al. (2009), Noorul Haq and Kannan (2006), Pi and Low (2006), and Xu et al. (2013).

Since AHP does not take into consideration the interdependency of criteria in the evaluation process, the application of ANP is recommended in situations where criteria are believed to be internally dependent. ANP is an extension of AHP and is well suited to handle dependency both within a cluster and among different clusters (Baskaran et al., 2012). The capability to flexibly incorporate major interdependencies among factors and clusters makes this technique superior to AHP and other multiattribute approaches. Moreover, the dynamic characteristics and complexity of the majority of decision-making environments make ANP a viable tool in dealing with such situations (Sarkis, 2003). According to Sarkis (2003), ANP is a robust decision-making technique for analyzing major issues concerning green supply chain management and environmental business practices, both of which require

Table 3
ANP applications in supplier selection.

Approach	Main purpose	Author(s)
ANP, DEA	To propose a framework for evaluating environmentally conscious manufacturing programs	Sarkis (1999)
ANP	Advancing the use of ANP as an effective and more realistic modeling approach in supplier selection	Sarkis and Talluri (2002)
ANP	To present a strategic decision framework for evaluation of green supply chain alternatives	Sarkis (2003)
ANP	Implementing an ANP model in an electronic company to evaluate and select the best supplier	Gencer and Gurpinar (2007)
ANN, DEA, ANP	To develop a green supplier selection model outperforming two other hybrid methods: ANN-DEA and ANP-DEA	Kuo et al. (2010)
ANP, AHP	To propose a supplier selection model in global supply chains under fuzzy environment	Yücenur et al. (2011)
DEMATEL, ANP, TOPSIS	To present a novel hybrid fuzzy MCDM approach to evaluate green suppliers	Büyüközkan and Çifçi (2012)
ANP, LP	To integrate fuzzy ANP and fuzzy multi-objective linear programming for supplier selection under uncertainty	Lin (2012)

strategic decision-making. Table 3 summarizes a number of ANP applications in supplier selection.

The technique for order preference by similarity to ideal solution (TOPSIS) is also one of the methods used by researchers in supplier selection decisions. The use of TOPSIS for supplier assessment has attracted researchers' attention in recent years. A number of supply chain studies making use of this technique include the works of Awasthi et al. (2010), Chen et al. (2006), Govindan et al. (2013), and Shen et al. (2013). According to Shih et al. (2007), the major weaknesses of TOPSIS are in not providing for weight elicitation, and consistency checking for judgments. Another problem attributable to TOPSIS is that it can cause a phenomenon known as 'total rank reversal' where the order of preferences is totally inverted with the inclusion or removal of an alternative from the decision problem; meaning that the alternative considered the best, becomes the worst (García-Cascales and Lamata, 2012).

Grey-based methods are able to capture, process, and integrate uncertainty in the decision-making process. They are specifically capable of handling complex problems involving both complete and incomplete information, making them superior to traditional decision-making techniques (Golmohammadi and Mellat-Parast, 2012). This capability to handle incomplete information is more realistic and more effective in some data poor environments (Bai and Sarkis, 2010a). Although fuzzy theory can also be used to deal with uncertainty (Bellman and Zadeh, 1970; Zadeh, 1965), there are some advantages for choosing Grey theory (Deng, 1989) over fuzzy theory. Firstly, the Grey approach considers the condition of fuzziness and flexibility regarding the inconsistent information in group decision-making situations (Baskaran et al., 2012; Deng, 1989). Secondly, the initial representation of criteria in fuzzy theory uses linguistic values, which are then transformed into known exact values. In the case of Grey theory, however, the fuzziness represented in criteria using linguistic values continues until the estimation of the weights and the assessment of the alternatives (Baskaran et al., 2012; Zhang et al., 2005). Another major advantage of Grey system theory is that it can achieve satisfactory outcomes using a rather small amount of data or with a large amount of variability in the factors (Fu et al., 2012). For these reasons, GRA has been suggested as one of the best methods for decision-making in the business environment (Golmohammadi and Mellat-Parast, 2012; Wu, 2002). A summary of the major Grey-based studies in decision-making and supplier selection is presented in Table 4.

Although several decision-making models in the literature have been developed based on the GRA, a number of drawbacks and limitations are associated with the existing models. One major issue deals with the aggregation of the decision-makers' preferences, where there has either been a lack of a weighting method or the use of a simple arithmetic mean of different opinions for weighting the criteria. This approach suffers from the disadvantage that it ignores the possible judgment bias of the decision-makers and does not check for any possible inconsistencies. In reviewing the literature, we find several examples of this approach including the works of Baskaran et al. (2012), Guo et al. (2009), Lee and Lin (2011), and Li et al. (2007). Another important limitation of the existing models is that they assume the criteria to be internally independent and do not take into account the possible interdependencies among them. An example of this approach is the study of Golmohammadi and Mellat-Parast (2012) where they applied an integrated fuzzy pairwise comparison matrix and GRA to develop a supplier selection model using conventional criteria such as price, quality, delivery, transportation cost, and technology. Although their research study addresses the judgment bias of the experts, it fails to take into consideration the inherent interdependencies among the supplier selection criteria. Other examples of this approach in the literature include the studies carried out by Hamzaçebi and Pekkaya (2011), Pophali et al. (2011), Xu et al. (2011), and Yang and Chen (2006). The third important limitation we aim to discuss deals with the studies employing other techniques such as a multi-objective optimization model by considering Grey relational degrees, examples of which include the works of Wei (2010) and Zhang et al. (2011). In their proposed models, the weights of the criteria were considered as variables and the Grey relational degrees as parameters of the model. We believe that using this approach for obtaining the weights of the criteria is inconsistent with the process of decision-making models, since alternatives are often evaluated by knowing the weights of the criteria beforehand.

Therefore, integrating the two methods (ANP and IGRA) maximizes the advantages of both and addresses the aforementioned drawbacks in the existing models. This combination also facilitates the multi-objective performance evaluation of suppliers. Hence, a novel comprehensive evaluation method combining ANP and IGRA is proposed to achieve a multi-criteria evaluation. The hierarchical and network structure of evaluation is established first, and the Grey relational coefficient matrix is obtained through the IGRA methodology subsequently.

3. Research methods

3.1. Analytic network process

AHP and ANP are the two most significant and popular MCDM methods aiding the decision makers to select the best choice under situations characterized by having more than one criterion. AHP, introduced by Saaty (1980), is a useful approach in solving complex decision problems. ANP was proposed by Saaty (1996) for extending the AHP to address restrictions of the hierarchical structure where criteria are independent from each other. The structural difference between AHP (hierarchy) and ANP (network) is shown in Fig. 1. As can be seen in Fig. 1, a hierarchy is the simple and special case of a network.

While nodes of the network show components of the system, arcs represent interactions between them. In order to build the decision problem, all interactions among elements of the system should be considered. As shown in Fig. 1b, $Goal \rightarrow Cluster1$ means that elements of Cluster1 depend on component Goal, so for

Table 4
Grey applications in decision-making and supplier selection.

Approach	Main purpose	Author(s)
Grey related analysis	To present the method of Grey related analysis to deal with uncertainty in decision-making	Zhang et al. (2005)
AHP, GRA	To develop an evaluation model considering qualitative and quantitative criteria for supplier selection in an outsourcing manufacturing organization	Yang and Chen (2006)
Grey theory	Proposing a new Grey-based approach to deal with the supplier selection problem	Li et al. (2007)
GRA, rough set theory	To propose a Grey-based rough decision-making approach to supplier selection	Li et al. (2008)
Grey theory, rough set theory	Using grey system and rough set methodologies to incorporate sustainability into supplier selection	Bai and Sarkis (2010b)
Grey theory	To evaluate suppliers within the textile and clothing industry using sustainability criteria	Baskaran et al. (2012)
Grey-based DEMATEL	To introduce a model for evaluating green supplier development programs, their relationships with each other, and their importance for the organization	Fu et al. (2012)
GRA, fuzzy pairwise comparison matrix	To develop a decision-making model for supplier selection based on GRA	Golmohammadi and Mellat-Parast (2012)

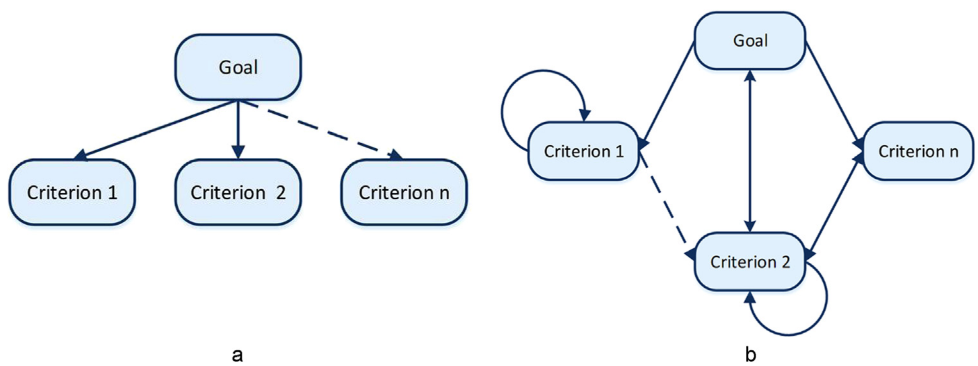

Fig. 1. AHP and ANP structure.

example Cluster1 and Cluster2 are interrelated in Fig. 1b i.e. a two-way arrow or arcs among different levels of elements may graphically represent the interdependencies in an ANP model. If there are interdependencies within the same level of analysis, a looped arc may be used to represent such interdependencies (see Fig. 1b). ANP allows both interaction and feedback within criteria (inner dependence) and between clusters (outer dependence). In fact, ANP uses a network without the need to designate levels as in a hierarchy. A network has two components, i.e. (a) a control hierarchy or network of criteria and sub-criteria that controls the interactions, and (b) a network of influences among the components and their clusters.

There are two types of 'control criteria' or 'level criteria' (Saaty and Varges, 2006). If the structure is a hierarchy, a control criterion may be directly connected to the decision structure as the goal of a hierarchy. In this case, the control criterion is called a comparison 'linking' criterion. On the other hand, a control criterion which does not connect directly to the structure but 'induces' comparisons in a network is called an 'inducing' criterion. The generic question to be answered by making pairwise comparisons is: Given a control criterion and a pair of components (elements), how much more does a given member of the pair influence that component with respect to the control criterion (sub-criterion) compared to the other member (Saaty and Varges, 2006)?

ANP uses ratio scale measurements based on pairwise comparisons. It uses a 1–9 scale measurement proposed by Saaty and Varges (2006) to compare elements reciprocally one by one similar to the AHP (see Table 5). The super-matrix representation of the ANP model used in this study is shown as follows:

$$\begin{array}{c} \\ Goal \\ Criteria \\ Sub-criteria \end{array} \begin{array}{c} \begin{array}{ccc} Goal & Criteria & Sub-criteria \end{array} \\ \begin{bmatrix} 0 & 0 & 0 \\ W_{21} & 0 & 0 \\ 0 & W_{32} & W_{33} \end{bmatrix} \end{array} \quad (1)$$

where W_{21} is a vector representing the impact of the goal on the criteria, W_{32} is a matrix representing the impact of the criteria on each of the sub-criteria, and finally W_{33} is the matrix that represents the inner dependencies between the sub-criteria.

All relations evaluated by pairwise comparisons and a super-matrix – a matrix of influence among the elements – are obtained by priority vectors. Finally, the cumulative influence of each element on every other element with which it interacts is obtained by raising the super-matrix to limiting powers in order to calculate the overall priorities. When a network consists of only two clusters apart from the goal, namely criteria and alternatives or criteria and sub-criteria, the matrix manipulation approach proposed by Saaty and Takizawa (1986) can be used to deal with dependencies of elements of a system. However, since in this paper ANP has been employed for weighting the criteria and sub-criteria, the second cluster comprises the sub-criteria in the model's network. Therefore, there is no third cluster associated with the alternatives. The network used in this paper is based on the structure of a hierarchy with inner dependencies within components and no feedback.

It should be noted that a matrix can have some more clusters and can also replace any zero value in the super-matrix if there is an interrelationship among elements within a cluster or between two clusters. Since there is usually interdependency among clusters in a network, the columns of a super-matrix may sum to more than one. However, the super-matrix must be modified so that each column of the matrix sums to unity (Saaty and Varges, 2006).

Saaty and Varges (2006) proposed the following four main steps of ANP as follows:

Step 1: *Model construction and problem structuring*: The problem should be clearly defined and decomposed into a logical system like a network.

Table 5
Fundamental scale for paired comparisons (Saaty and Varges, 2006).

Number[a]	Importance definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong Importance	Experience and judgment strongly favor one activity over another
7	Very strong demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

[a] There is no limitation for using the numbers 2, 4, 6 and 8.

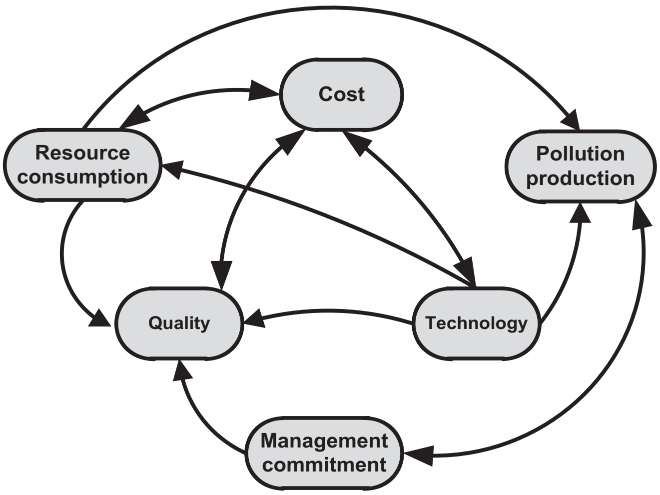

Fig. 2. Network of interactions between the sub-criteria.

Table 6
The random average indices.

N	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Step 2: Pairwise comparison matrices and priority vectors: Similar to AHP, pairs of decision elements at each cluster are compared one by one in terms of their importance towards their control criteria. The decision-maker (DM) is asked to respond to a series of pairwise comparisons of two elements or two clusters to be evaluated in terms of their contribution to their particular upper level criteria. In addition, interdependencies among elements of a cluster (here sub-criteria) must also be examined where the impact of each element on other elements can be represented by an eigenvector. Based on the opinions of experts, interdependencies among the sub-criteria are identified and presented in Fig. 2. For every pairwise comparison matrix, the consistency of logical judgment should be checked using the Consistency Index (CI) and Consistency Ratio (CR).
For each paired comparison matrix, CI should be used to check the consistency of the matrix as follows:

$$CI = \frac{1}{n-1}(\lambda_{\max} - n) \tag{2}$$

$$CR = \frac{CI}{RI} \tag{3}$$

The random average indices (RI) has been proposed by Saaty (1980) for various n representing the number of criteria in a pairwise comparison matrix, as shown in Table 6. If $CR \leq 0.1$, the pairwise comparison matrix is consistent.
Step 3: *Forming the super-matrix*: The local priorities are entered in the appropriate columns of a super-matrix to obtain the global priorities in a system with interdependent influences. As a result, a super-matrix is created which is in fact a partitioned matrix, where each segment represents a relationship between two clusters in a system. Generally, the super-matrix will be un-weighted. The super-matrix needs to be stochastic in order to derive meaningful limiting priorities. For this reason, we should normalize each column of the un-weighted super-matrix in order to obtain a weighted one.
Step 4: *Selecting the best alternatives or weighting attributes*: Finally, after the super-matrix is assured of being column stochastic, it is raised to a sufficiently large power until convergence occurs (Saaty, 1996). In other words, the super-matrix is raised to limiting powers $(2k+1)$ to become W^{2k+1}, where k is an arbitrarily large number, in order to obtain a steady-state outcome. Now, the relative weights of the elements can be found in the limiting super-matrix rows.

3.2. Improved Grey relational analysis

GRA is part of the Grey system theory (Mora´n et al., 2006), which mainly involves ambiguous or uncertain problems and situations with discrete data and incomplete information (Deng, 1989). Since the traditional GRA addresses uncertainty by considering deterministic numbers (Kuo et al., 2008; Lee and Lin, 2011; Tseng, 2010), an improved GRA with the ability to address interval numbers is presented in this paper. The improved Grey relational analysis method developed in this study is slightly different from that of Manzardo et al. (2012) in the sense that we have postponed the process of whitening the interval numbers to the final step. In addition, our proposed approach integrates the opinions of experts in the form of Grey numbers.

Generally, a Grey number is written as $\otimes G = \left[\underline{G}, \overline{G}\right]$, where $\underline{G}$ is the lower limit, and $\overline{G}$ the upper limit. Let $\otimes G_1$ and $\otimes G_2$ be two Grey numbers, and a be a crisp number, then the main operations needed for improved GRA are as follows (all parameters such as $a, \overline{G}_1, \underline{G}_1, \overline{G}_2,$ and $\underline{G}_2$ are greater than zero):

$$\otimes G_1 + \otimes G_2 = \left[\underline{G}_1 + \underline{G}_2, \overline{G}_1 + \overline{G}_2\right] \tag{4}$$

$$\otimes G_1 - \otimes G_2 = \left[\underline{G}_1 - \overline{G}_2, \overline{G}_1 - \underline{G}_2\right] \tag{5}$$

$$\frac{\otimes G_1}{a} = \left[\frac{\underline{G}_1}{a}, \frac{\overline{G}_1}{a}\right] \tag{6}$$

$$a \times \otimes G_1 = [a\underline{G}_1, a\overline{G}_1] \tag{7}$$

Assume that there are m alternatives characterized by n criteria, and the decision-making matrix given by the kth expert is shown as follows:

$$\otimes G^k = \begin{bmatrix} \otimes G_{11}^k & \otimes G_{12}^k & \cdots & \otimes G_{1n}^k \\ \otimes G_{21}^k & \otimes G_{22}^k & \cdots & \otimes G_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ \otimes G_{m1}^k & \otimes G_{m2}^k & \cdots & \otimes G_{mn}^k \end{bmatrix} \tag{8}$$

where $\otimes G_{ij}^k$ represents the value of the jth criterion of the ith alternative evaluated by the kth expert.

The proposed improved GRA method consists of several steps as follows:

Step 1: *Normalizing the decision-making matrix*: We use Eqs. (9) and (10) respectively to normalize the benefit criteria and the cost criteria:

$$\otimes y_{ij}^k = \frac{\otimes G_{ij}^k}{\max_{i=1}^m \left\{\overline{G}_{ij}^k\right\}}, \quad i=1,2,\ldots,m; \quad j=1,2,\ldots,n; \quad j \in \text{benefit criteria} \tag{9}$$

$$\otimes y_{ij}^k = \frac{\min_{i=1}^m \left\{\underline{G}_{ij}^k\right\}}{\otimes G_{ij}^k}, \quad i=1,2,\ldots,m; \quad j=1,2,\ldots,n; \quad j \in \text{cost criteria} \tag{10}$$

where $\otimes y_{ij}^k$ is the element of the normalized matrix.

After normalizing the decision matrix, all performance values are scaled into [0,1]. Now we define the reference sequence.

Step 2: *Generating the reference alternative*: We use Eqs. (11) and (12) to determine the reference alternative as follows:

$$y^{k,0} = \left\{y_1^{k,0}, y_2^{k,0}, \ldots, y_n^{k,0}\right\} \tag{11}$$

$$\otimes y_j^{k,0} = (\max_{i=1}^m \underline{y}_{ij}^k, \max_{i=1}^m \overline{y}_{ij}^k), \quad j=1,2,\ldots,n \tag{12}$$

where $y_j^{k,0}$ is the reference value in relation to the jth criterion, and y_{ij}^k are from the normalized matrix obtained from Eqs. (9) and (10).

Step 3: We calculate the difference between the alternatives and the reference alternative and construct the difference matrix as shown by

$$\otimes \Delta^k = \begin{bmatrix} \otimes \Delta_{11}^k & \otimes \Delta_{12}^k & \cdots & \otimes \Delta_{1n}^k \\ \otimes \Delta_{21}^k & \otimes \Delta_{22}^k & \cdots & \otimes \Delta_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ \otimes \Delta_{m1}^k & \otimes \Delta_{m2}^k & \cdots & \otimes \Delta_{mn}^k \end{bmatrix} \tag{13}$$

$$\otimes \Delta_{ij}^k = \left[y_j^{k,0} - \overline{y}_{ij}^k, y_j^{k,0} - \underline{y}_{ij}^k\right], \quad i=1,2,\ldots,m; \quad j=1,2,\ldots,n \tag{14}$$

Step 4: We calculate the Grey relational coefficient for all alternatives as shown by

$$\otimes \gamma_{ij}^k = \left[\underline{\gamma}_{ij}^k, \overline{\gamma}_{ij}^k\right] \tag{15}$$

$$\underline{\gamma}_{ij}^k = \frac{\min_{i=1}^m \min_{j=1}^n \underline{\Delta}_{ij}^k + \rho \max_{i=1}^m \max_{j=1}^n \overline{\Delta}_{ij}^k}{\overline{\Delta}_{ij}^k + \rho \max_{i=1}^m \max_{j=1}^n \overline{\Delta}_{ij}^k} \tag{16}$$

$$\overline{\gamma}_{ij}^k = \frac{\min_{i=1}^m \min_{j=1}^n \underline{\Delta}_{ij}^k + \rho \max_{i=1}^m \max_{j=1}^n \overline{\Delta}_{ij}^k}{\underline{\Delta}_{ij}^k + \rho \max_{i=1}^m \max_{j=1}^n \overline{\Delta}_{ij}^k} \tag{17}$$

where $\otimes \gamma_{ij}^k$ is the Grey relational coefficient, and ρ represents the distinguishing coefficient, taking the value of 0.5 in this paper. The smaller ρ the greater its distinguishing power. The value of ρ reflects the degree to which the minimum scores are emphasized relative to the maximum scores (Zhang et al., 2005).

Step 5: *Calculating the Grey relational degree for each alternative by the kth expert*: A Grey relational degree is a weighted sum of the Grey relational coefficients, as shown in Eq. (18):

$$\otimes \Gamma_i^k = \sum_{j=1}^n \otimes \gamma_{ij}^k \times w_j \tag{18}$$

Step 6: *Carrying out group decision-making*: We calculate the integrated lower and upper relational degrees of the alternatives according to Eqs. (19) and (20) as follows:

$$\underline{\Gamma}_i = \prod_{k=1}^L (\underline{\Gamma}_i^k)^{w_k} \tag{19}$$

$$\underline{\Gamma}_i = \prod_{k=1}^L (\overline{\Gamma}_i^k)^{w_k} \tag{20}$$

Step 7: *Whitening the Grey relational degrees*: The Grey relational degrees are whitened by using Eq. (21). The alternatives are then ranked according to the rule that the bigger the integrated whitened relational degree, the better the corresponding alternative.

$$\Gamma_i = \frac{\underline{\Gamma}_i + \overline{\Gamma}_i}{2} \tag{21}$$

4. Proposed approach

Our proposed procedure for green supplier selection consists of five steps, as shown in Fig. 3.

The first step of the proposed procedure is to identify and preselect suppliers based on the implementation of environmental management systems such as the ISO 14000 series. This preselection allowed us to make sure that all suppliers were evaluated by green criteria. In the second step of the procedure, we identified and selected relevant criteria for green supplier selection by

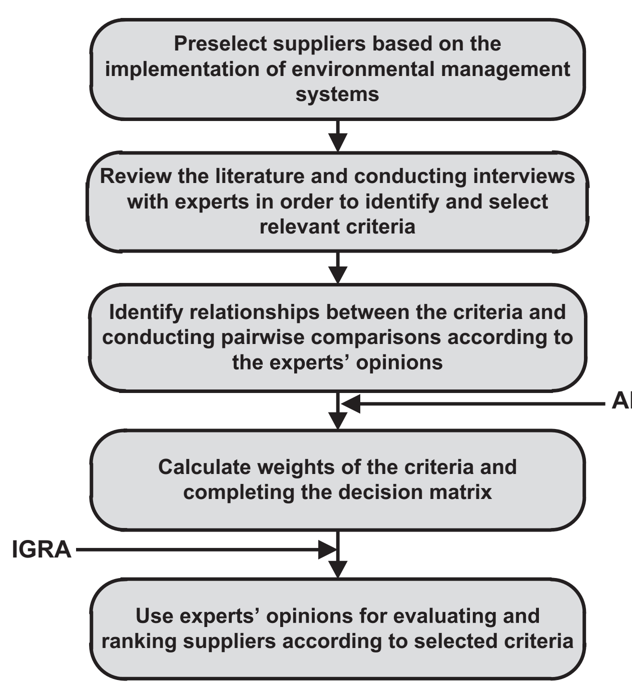

Fig. 3. Proposed green supplier selection procedure.

reviewing the literature and conducting interviews with experts. In this study, we made use of a structured questionnaire filled out by experts in order to approve and select the relevant criteria based upon those suggested by the literature. In order to ensure that all chosen criteria were relevant for our case company, a questionnaire was designed in which experts were asked to provide their opinions on whether a criteria was relevant or not; inserting number 1 if relevant and 0 if non-relevant. Next, the criteria which received the unanimous approval of all experts were considered as relevant and chosen for further analysis. In addition, the experts were asked to recommend any criteria possibly not considered in our literature review, but no extra criteria was proposed. Therefore, the relevance of the criteria for the case company was taken into account and we made sure that there was a unanimous agreement among all experts for approving each of the criteria mentioned in Fig. 2.

Moreover, the experts were asked to provide their opinions on the relationships between the chosen criteria in a relation matrix, where they inserted number 1 in case there was a relationship between two selected criteria and 0 if no relationship was assumed. For aggregating different opinions, we considered the 'mode' of opinions for each cell as discussed by Warfield (1974), meaning that a relationship was assumed between two criteria if three or more experts approved the existence of such a relationship. This step is also part of the analysis in the interpretive structural modeling (ISM) method. Table 7 shows the aggregated relation matrix for interrelationships among the criteria. Some studies in the literature have previously considered interrelationships among supplier selection criteria by using methods such as ISM, DEMATEL, and ANP (Büyüközkan and Çifçi, 2012). For instance, a number of scholars have pointed out the existence of internal relationships between quality, price, and technology and also between price and technology (Golmohammadi and Mellat-Parast, 2012; Yang et al., 2008).

Finally, using pairwise comparisons in order to determine the relative importance of the criteria, we calculated the weights of the criteria by using a super-matrix which is part of the ANP. After obtaining relative weights of the criteria in the fourth step, our decision matrix would be completed. Finally, by measuring the experts' opinions in linguistic terms, the final scores of the green suppliers were calculated by the improved GRA method.

5. A case study

Over the past decades, there has been mounting pressure on the automobile manufacturers to actively improve their supply chain environmental performance and to reduce the negative environmental impacts of their operations (Olugu et al., 2011). Globalization may result in both stronger drivers and opportunities for many enterprises to improve their environmental performance (Zhu et al., 2011), and Iranian automobile manufacturing companies are not exceptions. In order to gain a competitive advantage in the global environment, the Iranian automobile manufacturers have struggled to improve their economic and environmental performance within their entire supply chains. Exporting products and becoming suppliers for foreign companies are the main factors motivating the Iranian automobile manufacturing industry to implement GSCM practices. Accordingly, GSCM initiatives have started to slowly emerge to balance the economic and environmental performance of the automobile manufacturers in Iran. Since the majority of automobile components are outsourced to external suppliers, suppliers play a very vital role in greening the supply chains of the automobile manufacturing firms (Olugu et al., 2011).

Over three decades ago, the Sazeh Gostar Saipa Corporation was established in Iran as the first manufacturing company to design, engineer, and supply automobile parts nationwide. The company is currently providing the necessary parts for producing over 400,000 vehicles per year, and is planning to increase this number to 500,000 in the next two years. The company also implements ISO 14000 principles in its supply chain and collaborates with suppliers to improve their environmental performance. In order to fulfill its primary purpose, Saze Gostar is in constant need of polymeric materials provided by its own suppliers.

In this paper, the case of Saze Gostar is presented to demonstrate the applicability and efficacy of our proposed approach. A committee of four experts has been formed to evaluate five suppliers of polymeric materials, the names of which are redacted due to our confidentiality agreement with the Saze Gostar Corporation. The experts participated in this research were the logistics supervisor (E1), the chief executive officer (E2), the health, safety and environmental supervisor (E3), and the procurement manager (E4). It should be noted that we invited key decision-makers from the case company to participate in this study. For instance, the logistics supervisor (E1) managed the logistics department with six logistics specialists. All judgments provided by the logistics supervisor were in consultation with the members of the logistics department. The health, safety and environmental supervisor (E3) managed four health and safety specialists and his judgments and opinions were provided after consultation with his team of four health and safety specialists. Similarly, the procurement manager (E4) supervised seven procurement specialists and his decisions were made in consultation with the seven procurement specialists in his department. Finally, the chief executive officer (E2) judgments were used in the model after consultation with his management team which composed of 12 senior vice presidents.

In order to capture the uncertainty and incompleteness of the information, the experts were asked to express their judgments for evaluating the suppliers in linguistic terms. The framework for the integrated ANP-improved GRA supplier selection is shown in Fig. 4. According to ANP, in addition to the importance of the criteria and sub-criteria, the interrelationships between elements of the clusters should also be considered if they exist. Therefore, in this study, we sought the opinions of experts in order to determine the interdependencies between the sub-criteria (see Fig. 3).

To obtain more accurate assessment outputs, each expert was given a relative weight. Therefore, the relative weights for the experts in this study were assigned as 0.15, 0.25, 0.2, and 0.4 for E1, E2, E3, and E4 respectively. The relative weight for the procurement manager is the largest mainly because of his significant role

Table 7
Relation matrix of criteria interrelationships.

Criteria	Cost	Quality	Technology	Resource consumption	Pollution production	Management commitment
Cost	–	1	1	1	0	0
Quality	1	–	0	0	0	0
Technology	1	1	–	1	1	0
Resource consumption	1	1	0	–	1	0
Pollution production	0	0	0	0	–	1
Management commitment	0	1	0	0	1	–

in purchasing decisions. The second largest weight is assigned to the chief executive officer because he makes the final decision in the majority of purchasing decisions. To analyze the sensitivity for relative weights of the opinions, we considered several scenarios in Section 6 by taking into account different weights for the experts' opinions in order to check how the results would change under different conditions.

5.1. Phase 1: Calculating weights of the sub-criteria

A total of six pairwise matrices were constructed for the interdependence relationships among the sub-criteria and criteria, and the relative importance of the sub-criteria. In order to integrate the opinions of the four experts in this study, we utilized the geometric mean of values in the pairwise comparison matrices, the results of which are presented in Tables 8 and 9. The eigenvectors for the interdependence matrices were calculated in a similar manner and are presented in Tables 10–13. In addition, the normalized inner dependency matrix for the sub-criteria is presented in Table 14.

The super-matrix which measures interdependence can then be obtained by combining the results obtained by calculating W_{21} (see Table 9), W_{32}(see Table 8) and W_{33} (see Tables 10–14). The normalized super-matrix is shown in Table 15. In this paper, the limit super-matrix which has rows with a unique value has been obtained by raising the normalized matrix to 125. Therefore, the final relative weights of cost, quality, technology, resource consumption, pollution production and management commitment are 0.357, 0.157, 0.260, 0.128, 0.049 and 0.049 respectively (see the rows of Table 16).

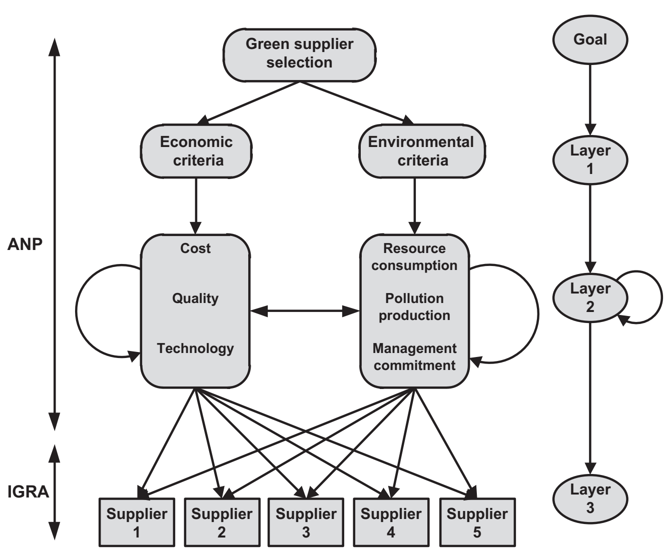

Fig. 4. Green supplier selection framework with economic and environmental criteria.

Table 8
Integrated paired-comparison matrix and relative weights of the sub-criteria.

	Cost	Quality	Technology	Resource consumption	Pollution production	Management commitment	Relative weights
Cost	1.000	1.569	3.241	3.325	2.603	3.565	0.318
Quality	0.637	1.000	0.501	2.000	1.850	2.603	0.165
Technology	0.309	1.995	1.000	1.516	5.264	2.305	0.227
Resource consumption	0.301	0.500	0.660	1.000	0.311	0.430	0.072
Pollution production	0.384	0.540	0.190	3.213	1.000	2.528	0.131
Management commitment	0.280	0.384	0.434	2.325	0.396	1.000	0.087
							CR = 0.096

5.2. Phase 2: Assessing green suppliers' performance

In this paper, the linguistic terms of "very good", "good", "medium", "poor", and "very poor" are used for performance evaluation of the suppliers according to different criteria, as shown in Table 17. The experts evaluate the performance of suppliers based upon their experience and judgment. In this phase, evaluators were asked to build the decision matrix by comparing the alternatives under each of the sub-criteria. The results of the

Table 9
Integrated paired-comparison matrix and relative weights of the criteria.

	Economic	Environmental	Relative weight
Economic	1.000	1.824	0.646
Environmental	0.548	1.000	0.354
			CR = 0.000

Table 10
Interdependence matrix of sub-criteria with respect to cost.

Cost	Quality	Technology	Resource consumption	Weights
Quality	1.000	1.414	1.927	0.440
Technology	0.707	1.000	2.176	0.364
Resource consumption	0.519	0.460	1.000	0.196
				CR = 0.014

Table 11
Interdependence matrix of sub-criteria with respect to quality.

Quality	Cost	Technology	Resource consumption	Management commitment	Weights
Cost	1.000	0.755	1.978	0.560	0.247
Technology	1.324	1.000	0.933	1.737	0.284
Resource consumption	0.506	1.072	1.000	1.677	0.246
Management commitment	1.787	0.576	0.596	1.000	0.222
					CR = 0.09

Table 12
Interdependence matrix of sub-criteria with respect to resource consumption.

Resource consumption	Technology	Cost	Weight
Technology	1.000	1.221	0.550
Cost	0.819	1.000	0.450
			Consistent

survey by the four experts are shown in Table 18. The Grey relational degrees, the whitening relational degrees and the ranks of the green suppliers as determined by the experts are shown in Table 19. All calculations were performed using Microsoft Excel.

Table 13
Interdependence matrix of sub-criteria with respect to pollution production.

Pollution production	Technology	Resource consumption	Management commitment	Weights
Technology	1.000	1.107	0.812	0.320
Resource consumption	0.904	1.000	1.824	0.389
Management commitment	1.231	0.548	1.000	0.291
				CR = 0.053

as follows:

Supplier 2 > Supplier 4 > Supplier 3 > Supplier 5 > Supplier 1

Therefore, it is concluded that supplier 2 has the best economic and environmental performance according to opinions of the experts.

Table 17
Scale of Grey numbers for the alternatives' assessment.

Linguistic variables	Scale of Grey number ($\otimes G$)
Very poor (VP)	(1.5,3.0)
Poor (P)	(3.0,4.5)
Medium (M)	(4.5,6.0)
Good (G)	(6.0,7.5)
Very good (VG)	(7.5,9.0)

Table 14
Interdependence normalized matrix of the sub-criteria evaluation.

Sub-criteria	Cost	Quality	Technology	Resource consumption	Pollution production	Management commitment
Cost	0.000	0.247	1.000	0.450	0.000	0.000
Quality	0.440	0.000	0.000	0.000	0.000	0.000
Technology	0.364	0.284	0.000	0.550	0.320	0.000
Resource consumption	0.196	0.246	0.000	0.000	0.389	0.000
Pollution production	0.000	0.000	0.000	0.000	0.000	1.000
Management commitment	0.000	0.222	0.000	0.000	0.291	0.000

Table 15
Weighted super-matrix.

Sub-criteria	Goal	Economic	Environmental	Cost	Quality	Technology	Resource consumption	Pollution production	Management commitment
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Economic	0.646	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Environmental	0.354	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cost	0.000	0.448	0.000	0.000	0.247	1.000	0.450	0.000	0.000
Quality	0.000	0.232	0.000	0.440	0.000	0.000	0.000	0.000	0.000
Technology	0.000	0.320	0.000	0.364	0.284	0.000	0.550	0.320	0.000
Resource consumption	0.000	0.000	0.248	0.196	0.246	0.000	0.000	0.389	0.000
Pollution production	0.000	0.000	0.452	0.000	0.000	0.000	0.000	0.000	1.000
Management commitment	0.000	0.000	0.300	0.000	0.222	0.000	0.000	0.291	0.000

Table 16
Limit super-matrix.

Sub-criteria	Goal	Economic	Environmental	Cost	Quality	Technology	Resource consumption	Pollution production	Management commitment
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Economic	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Environmental	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cost	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357
Quality	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.157
Technology	0.260	0.260	0.260	0.260	0.260	0.260	0.260	0.260	0.260
Resource consumption	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128
Pollution production	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049
Management commitment	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049

6. Results and sensitivity analysis

The final results of the improved GRA method are summarized in Table 18. Based on the white Grey relational degrees, the ranking order of the suppliers according to green performance is

Next, we conducted sensitivity analyses on the decision parameters to study changes in the order of suppliers when different scenarios are imposed. Initially, we tested the sensitivity of the results by making changes to both the set of criteria and decision-makers in scenarios 1–6. Secondly, we altered the relative weights of experts' opinions while maintaining all criteria in scenarios 7–11 (see Table 20). Different scenarios for weighting the opinions of experts were considered. In each of these scenarios, one expert had a dominant weight. In addition, a scenario where all opinions were weighted equally was investigated. Table 20 summarizes the supplier ranking for different scenarios, and Fig. 5 illustrates a graphical representation of these results. Generally, it was concluded that the results of the research were dependent on the relative weights of experts' opinions. As presented in Table 20 and Fig. 5, the results of the sensitivity analysis show that although there were no significant changes in the ranking order of S2, significant changes were observed in the ranking orders of other suppliers.

Another type of sensitivity analysis which has been proposed by Belton and Gear (1982) is rank reversal analysis. They observed that by adding new copies of an alternative to a decision problem, it was possible that there was a change in the ranking of alternatives. Indeed, a number of authors have expressed their opinions on this subject, referring to this phenomenon with the name of rank reversal (García-Cascales and Lamata, 2012; Saaty and Sagir, 2009; Saaty and Vargas, 1984, 1993). In this section of our sensitivity analysis, we considered nine extra scenarios by adding or eliminating a supplier in order to test the occurrence of rank reversal in the GRA methodology. In each of the scenarios 12–15, we added a new supplier (S6) with a performance level equal to the average performance levels of two consecutive suppliers and we attempted to test whether our proposed methodology had rank reversal in terms of adding new alternatives. Our rank reversal analysis is based on the opinion of E1 and as can be seen in Table 20, he has ranked the suppliers in the following order: S2 > S4 > S5 > S3 > S1. As a result, the performance of S6 was assumed as the average performance levels of S2 and S4 in scenario 12, the average performance levels of S4 and S5 in scenario 13, the average performance levels of S5 and S3 in scenario 14, and the average performance levels of S3 and S1 in scenario 15. The results indicated that there were no changes in the ranking order of the suppliers. Therefore, the proposed methodology did not exhibit rank reversal in terms of adding new suppliers. In each of the scenarios 16–20, one of the suppliers was excluded from the analysis. By eliminating S2 in scenario 16, and S3 in scenario 19, we saw that the ranking order of S4 and S5 was reversed. However, the ranking order of suppliers remained intact in scenarios 17, 18 and 20. Therefore, it was concluded that rank reversal occurred in some scenarios after eliminating one of the suppliers. Saaty and

Table 18
Linguistic assessment of the suppliers by experts.

Criteria	Experts	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Cost	E1	VP	P	VP	M	P
	E2	P	M	G	G	M
	E3	M	M	M	M	P
	E4	P	G	P	G	G
Quality	E1	M	G	M	P	M
	E2	M	G	G	M	M
	E3	P	G	M	G	P
	E4	P	P	G	M	P
Technology	E1	M	G	G	M	VG
	E2	M	VG	VG	G	M
	E3	G	G	M	M	P
	E4	M	M	G	M	G
Resource consumption	E1	P	M	G	P	M
	E2	M	VG	M	VP	G
	E3	G	M	M	M	G
	E4	P	G	M	P	M
Pollution production	E1	P	G	M	P	VP
	E2	M	M	P	M	P
	E3	P	G	VP	P	G
	E4	G	P	P	M	G
Management commitment	E1	P	G	M	G	M
	E2	M	VG	P	VG	M
	E3	G	G	M	M	P
	E4	M	P	G	M	P

Table 19
Suppliers' Grey relational degree for each expert, integrated lower and upper relational degree of the alternatives and their whitening relational degrees.

Alternatives	$\otimes\Gamma_i^k$				$(\underline{\Gamma}_i,\overline{\Gamma}_i)$	Γ_i	Ranks
	E1	E2	E3	E4			
Supplier 1	(0.467,0.524)	(0.523,0.571)	(0.882,0.894)	(0.418,0.468)	(0.522,0.569)	0.521	5
Supplier 2	(0.690,0.733)	(0.863,0.881)	(0.949,0.955)	(0.700,0.728)	(0.782,0.807)	0.795	1
Supplier 3	(0.579,0.627)	(0.884,0.896)	(0.730,0.763)	(0.665,0.693)	(0.713,0.742)	0.727	3
Supplier 4	(0.675,0.705)	(0.768,0.791)	(0.797,0.823)	(0.657,0.692)	(0.713,0.743)	0.728	2
Supplier 5	(0.666,0.711)	(0.583,0.632)	(0.566,0.617)	(0.799,0.816)	(0.671,0.709)	0.690	4

Table 20
Supplier ranking for different scenarios.

Scenario	Decision criteria	Decision-makers	Supplier ranking
Initial condition	All criteria	E1(0.15), E2(0.25), E3(0.2), E4(0.4)	2 > 4 > 3 > 5 > 1
Scenario1	Economic criteria only	E1(0.15), E2(0.25), E3(0.2), E4(0.4)	2 > 4 > 3 > 5 > 1
Scenario2	Environmental criteria only	E1(0.15), E2(0.25), E3(0.2), E4(0.4)	2 > 5 > 1 > 3 > 4
Scenario3	All criteria	E1	2 > 4 > 5 > 3 > 1
Scenario4	All criteria	E2	3 > 2 > 4 > 5 > 1
Scenario5	All criteria	E3	2 > 1 > 4 > 3 > 5
Scenario6	All criteria	E4	5 > 2 > 3 > 4 > 1
Scenario7	All criteria	E1(0.15), E2(0.15), E3(0.2), E4(0.5)	2 > 4 > 5 > 3 > 1
Scenario8	All criteria	E1(0.2), E2(0.15), E3(0.5), E4(0.15)	2 > 4 > 3 > 1 > 5
Scenario9	All criteria	E1(0.5), E2(0.15), E3(0.2), E4(0.15)	2 > 4 > 3 > 5 > 1
Scenario10	All criteria	E1(0.2), E2(0.5), E3(0.15), E4(0.15)	2 > 3 > 4 > 5 > 1
Scenario11	All criteria	E1(0.25), E2(0.25), E3(0.25), E4(0.25)	2 > 4 > 3 > 5 > 1

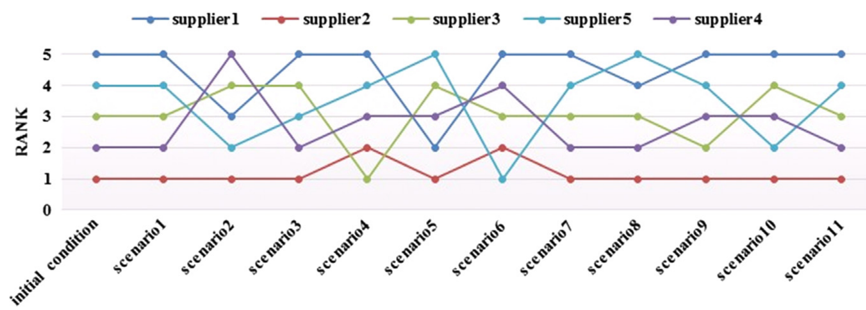

Fig. 5. Sensitivity analysis.

Vargas (1984) argue that rank reversal does occur, should be acceptable and "there is no law of nature that prohibits such a way of thinking". On the other hand, we should also consider that "if an act is non-optimal for a decision problem under uncertainty, it cannot be made optimal by adding new acts to the problem" (Luce and Raiffa, 1957).

According to the results of the sensitivity analysis, applying different scenarios causes changes in the sequence of suppliers. But although the ranking order of green suppliers change with respect to different experts' opinions, S2 is generally selected as the best supplier. This could be attributed to the fact that there is general agreement among all four experts that S2 is the most appropriate supplier. It should also be noted that because of the higher weight given to the economic criteria especially the 'cost' criterion, the results of scenario 1 and the initial condition became similar. This could be because the case company has not yet reached maturity in terms of greenness and managers still have greater emphasis on economic criteria compared to environmental criteria. Saaty and Vargas (1984) also argue that eliminating criteria with lower weights does not often cause rank reversal and the ranking order of alternatives remain unchanged in such a case. However, the situation would change as the company becomes greener. Since the decision-making process is sensitive to the type of criteria, the number of participants involved, and their expertise with the subject, their selection should be carried out carefully.

7. Managerial implications

The proposed framework in this study encompasses economic and environmental standards that can be used to shape an evaluation platform for green performance of automobile manufacturing corporations and their suppliers. The framework can specifically provide supply chain managers in developing countries with a better understanding regarding the application of green practices in manufacturing firms. The authors believe that the internal relationships among green supplier evaluation criteria are generally not taken into account by supply chain decision-makers. This issue stems partly from the complexity of the required calculations and more importantly from lack of enough knowledge among supply chain managers regarding these interactions. This study specifically stresses the importance of taking into consideration such interrelationships by utilizing ANP.

Although criteria such as cost and quality are generally given the highest priority in the traditional supplier selection problems, it is important to mention that these criteria are very much dependent on other criteria such as 'technology' and 'management commitment' (see Fig. 2). Despite the fact that the traditional criteria might be more transparent in terms of performance evaluation, managers should give specific attention to the driving criteria such as 'technology' if they aim to increase the overall sustainability performance of their organizations. In other words, it would be essential to focus on the cause group criteria in advance due to their influences on the effect group criteria (Fontela and Gabus, 1976). Thus, this study suggests that managers should take interactions among the criteria into serious consideration on the path towards greening the automobile manufacturing firms.

As a developing country, Iran highlights economic development as a priority; but demands for economic modernization would bring about huge environmental impacts. With internationalization, the Iranian companies would have to compete with their foreign competitors. Given the fact that competition no longer takes place between companies, but between supply chains (Andiç et al., 2012), manufacturing firms in developing countries need to consider the integration of GSCM practices in order to remain competitive. One such possible initiative could be the inclusion of a systematic supplier evaluation program. Supplier selection in GSCM is clearly a critical decision in purchasing management because a firm's environmental sustainability and ecological performance can be demonstrated by its suppliers (Kuo et al., 2010). By implementing green supplier evaluation programs, businesses could identify and prioritize opportunities for improving their economic and environmental performance. This would in turn lead to a reduction in the negative environmental impacts of their activities and an increase in their economic benefits as well.

8. Conclusions and future research directions

The growing number of manufacturing firms around the world has created many new business opportunities, but has also caused a substantial environmental burden (Rao, 2002). The GSCM has emerged as an influential method for mitigating the negative consequences of business operations on the environment. In this paper, we presented a green supplier selection model using an integrated ANP-improved GRA approach to evaluate and choose the best green supplier by considering both environmental and economic criteria. The model was implemented in a case study of the automotive industry. The ANP was applied in order to obtain relative weights of the sub-criteria, taking into account their internal dependencies. Based on the literature survey and approval of the experts, possible green supplier evaluation criteria were identified and a new evaluation model was formulated. In addition, we utilized the improved GRA in order to rank the suppliers based on their economic and environmental performance. The improved GRA method proposed in this study is a powerful decision-making tool dealing with uncertainty by the use of interval numbers. One of the advantages of the improved GRA over other decision-making techniques is that in this method, the opinions of experts can be gathered separately and then integrated into the model. This makes our proposed model more flexible compared to other models utilizing methods such as TOPSIS or AHP, in which opinions have to be integrated at the beginning of the process. This flexibility is specifically very useful in conducting sensitivity analysis of the results where new opinions may be added or previous ones might be eliminated. In addition, while interdependencies among the criteria are not taken into account in the traditional GRA, our hybrid ANP-improved GRA approach has made this consideration possible. Thus, the green supplier selection model proposed in this study is novel and can be applied in other decision-making or supplier selection problems.

Moreover, major limitations of the existing Grey models were discussed comprehensively and relevant solutions to tackle these weaknesses were proposed. In summary, we make several important contributions to the body of knowledge of decision-making theory. The drawbacks such as simplification in weight assignment, lacking the basis to check for possible inconsistencies and ignoring the inherent interdependencies among the criteria were discussed and a new ANP-IGRA model was proposed to address these issues. Another major advantage of the proposed approach is that the whitening process of the Grey relational degrees was postponed to the final step, ensuring that uncertainty was maintained in all stages of the computations. In addition, the rank reversal sensitivity analysis for the GRA methodology has not been investigated previously in the literature.

While we believe that the proposed approach provides value, this study has some limitations. One of the limitations is that the results of the research are highly dependent on the experts' opinions. One possible solution to address this issue would be to increase the number of experts. Another limitation could be the relatively large number of pairwise comparisons needed to carry out the analysis. In such cases, fatigue is certainly a possibility which may cause some reliability problems. This issue could develop in situations where too many criteria have to be integrated into the model. Overall, this approach is flexible and useful for application in a broad range of managerial and decision-making environments. We believe this study sets the stage for future investigation into GSCM research.

Future research could expand the scope of this paper by analyzing the interrelationships among the criteria using methods such as the Decision Making Trial and Evaluation Laboratory (DEMATEL) or interpretive structural modeling (ISM). Responding to the growing concerns of customers and shareholders for corporate social responsibility (CSR), many purchasing firms are implementing programs within their supply chains in order to ensure that their suppliers are acting in a socially responsible way. Prospective studies could consider this kind of issue. In addition, since many decisions in the business world are based on political factors including dependence power and lobbying, the integration of a political dimension into the green supplier selection criteria would be useful. Recent reports suggest that at least 80% of the carbon emissions are released in the total supply chain (Hsu et al., 2013). However, although it is vital for organizations to reduce carbon risk by collaborating with suppliers, the consideration of carbon management in green supplier selection has rarely been discussed in the literature. Future studies could also focus on this environmental topic.

Acknowledgment

The authors would like to thank the anonymous reviewers and the editor-in-chief for their constructive comments and suggestions.

References

Alinezad, A., Seif, A., Esfandiari, N., 2013. Supplier evaluation and selection with QFD and FAHP in a pharmaceutical company. Int. J. Adv. Manuf. Technol. 68, 355–364.
Amin, S.H., Zhang, G., 2012. An integrated model for closed-loop supply chain configuration and supplier selection: multi-objective approach. Expert Syst. Appl. 39, 6782–6791.
Amindoust, A., Ahmed, S., Saghafinia, A., Bahreininejad, A., 2012. Sustainable supplier selection: a ranking model based on fuzzy inference system. Appl. Soft Comput. 12, 1668–1677.
Andiç, E., Yurt, Ö., Baltacıoğlu, T., 2012. Green supply chains: efforts and potential applications for the Turkish market. Resour. Conserv. Recycl. 58, 50–68.
Awasthi, A., Chauhan, S.S., Goyal, S.K., 2010. A fuzzy multicriteria approach for evaluating environmental performance of suppliers. Int. J. Prod. Econ. 126, 370–378.
Bai, C., Sarkis, J., 2010a. Green supplier development: analytical evaluation using rough set theory. J. Clean. Prod. 18, 1200–1210.
Bai, C., Sarkis, J., 2010b. Integrating sustainability into supplier selection with Grey system and rough set methodologies. Int. J. Prod. Econ. 124, 252–264.
Baskaran, V., Nachiappan, S., Rahman, S., 2012. Indian textile suppliers' sustainability evaluation using the Grey approach. Int. J. Prod. Econ. 135, 647–658.
Bellman, R.E., Zadeh, L.A., 1970. Decision-making in a fuzzy environment. Manag. Sci. 17, 141–164.
Belton, V., Gear, T., 1982. On a shortcoming of Saaty's method of analytic hierarchies. Omega 11, 226–230.
Büyüközkan, G., Çifçi, G., 2012. A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers. Expert Syst. Appl. 39, 3000–3011.
Chai, J., Liu, J.N.K., Ngai, E.W.T., 2013. Application of decision-making techniques in supplier selection: a systematic review of literature. Expert Syst. Appl. 40, 3872–3885.
Chan, F.T.S., 2003a. Interactive selection model for supplier selection process: an analytical hierarchy process approach. Int. J. Prod. Res. 41, 3549–3579.
Chan, F.T.S., 2003b. Performance measurement in a supply chain. Int. J. Adv. Manuf. Technol. 21, 534–548.
Chen, C.-T., Lin, C.-T., Huang, S.-F., 2006. A fuzzy approach for supplier evaluation and selection in supply chain management. Int. J. Prod. Econ. 102, 289–301.
Choi, T.Y., Hartley, J.L., 1996. An exploration of supplier selection practices across the supply chain. J. Oper. Manag. 14, 333–343.
de Boer, L., Labro, E., Morlacchi, P., 2001. A review of methods supporting supplier selection. Eur. J. Purch. Supply Manag. 7, 75–89.
Deng, J.L., 1989. The introduction of Grey system. J. Grey Syst. 1, 1–24.
Diabat, A., Khodaverdi, R., Olfat, L., 2013. An exploration of green supply chain practices and performances in an automotive industry. Int. J. Adv. Manuf. Technol. 68, 949–961.

Fontela, E., Gabus, A., 1976. The DEMATEL Observer. Battelle Geneva Research Center, Geneva, Switzerland.

Fu, X., Zhu, Q., Sarkis, J., 2012. Evaluating green supplier development programs at a telecommunications systems provider. Int. J. Prod. Econ. 140, 357–367.

García-Cascales, M.S., Lamata, M.T., 2012. On rank reversal and TOPSIS method. Math. Comput. Model. 56, 123–132.

Gencer, C., Gurpinar, D., 2007. Analytic network process in supplier selection: a case study in an electronic firm. Appl. Math. Model. 31, 2475–2486.

Ghodsypour, S.H., O'Brien, C., 1998. A decision support system for supplier selection using an integrated analytical hierarchy process and linear programming. Int. J. Prod. Econ. 56–57, 199–212.

Golmohammadi, D., Mellat-Parast, M., 2012. Developing a Grey-based decision-making model for supplier selection. Int. J. Prod. Econ. 137, 191–200.

Govindan, K., Khodaverdi, R., Jafarian, A., 2013. A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach. J. Clean. Prod. 47, 345–354.

Green, K., Morton, B., New, S., 1996. Purchasing and environmental management: interaction, policies and opportunities. Bus. Strategy Environ. 5, 188–197.

Guo, X., Yuan, Z., Tian, B., 2009. Supplier selection based on hierarchical potential support vector machine. Expert Syst. Appl. 36, 6978–6985.

Gupta, S., Krishnan, V., 1999. Integrated component and supplier selection for a product family. Prod. Oper. Manag. 8, 163–182.

Hamzaçebi, C., Pekkaya, M., 2011. Determining of stock investments with Grey relational analysis. Expert Syst. Appl. 38, 9186–9195.

Handfield, R., Walton, S.V., Sroufe, R., Melnyk, S.A., 2002. Applying environmental criteria to supplier assessment: a study in the application of the Analytical Hierarchy Process. Eur. J. Oper. Res. 141, 70–87.

Ho, W., Xu, X., Dey, P.K., 2010. Multi-criteria decision making approaches for supplier evaluation and selection: a literature review. Eur. J. Oper. Res. 202, 16–24.

Hsu, C.-W., Kuo, T.-C., Chen, S.-H., Hu, A.H., 2013. Using DEMATEL to develop a carbon management model of supplier selection in green supply chain management. J. Clean. Prod. 56, 164–172.

Humphreys, P., McIvor, R., Chan, F., 2003. Using case-based reasoning to evaluate supplier environmental management performance. Exp. Syst. Appl. 25, 141–153.

Kuo, R.J., Wang, Y.C., Tien, F.C., 2010. Integration of artificial neural network and MADA methods for green supplier selection. J. Clean. Prod. 18, 1161–1170.

Kuo, Y., Yang, T., Huang, G.-W., 2008. The use of Grey relational analysis in solving multiple attribute decision-making problems. Comput. Ind. Eng. 55, 80–93.

Lee, A.H.I., Kang, H.-Y., Hsu, C.-F., Hung, H.-C., 2009. A green supplier selection model for high-tech industry. Expert Syst. Appl. 36, 7917–7927.

Lee, W.-S., Lin, Y.-C., 2011. Evaluating and ranking energy performance of office buildings using Grey relational analysis. Energy 36, 2551–2556.

Li, G.-D., Yamaguchi, D., Nagai, M., 2007. A Grey-based decision-making approach to the supplier selection problem. Math. Comput. Model. 46, 573–581.

Li, G.-D., Yamaguchi, D., Nagai, M., 2008. A Grey-based rough decision-making approach to supplier selection. Int. J. Adv. Manuf. Technol. 36, 1032–1040.

Lin, R.-H., 2012. An integrated model for supplier selection under a fuzzy situation. Int. J. Prod. Econ. 138, 55–61.

Luce, R.D., Raiffa, H., 1957. Games and Decisions: Introduction and Critical Survey. John Wiley and Sons, New York.

Manzardo, A., Ren, J., Mazzi, A., Scipioni, A., 2012. A Grey-based group decision-making methodology for the selection of hydrogen technologies in life cycle sustainability perspective. Int. J. Hydrogen Energy 37, 17663–17670.

Messelbeck, J., Whaley, M., 1999. Greening the health care supply chain: triggers of change, models for success. Corp. Environ. Strategy 6, 39–45.

Mora´n, J., Granada, E., Mı´guez, J.L., Porteiro, J., 2006. Use of Grey relational analysis to assess and optimize small biomass boilers. Fuel Process. Technol. 87, 123–127.

Narasimhan, R., Carter, J.R., 1998. Environmental Supply Chain Management. The Center for Advanced Purchasing Studies, Arizona State University, Tempe, AZ, USA.

Noci, G., 1997. Designing green vendor rating systems for the assessment of a supplier's environmental performance. Eur. J. Purch. Supply Manag. 3, 103–114.

Noorul Haq, A., Kannan, G., 2006. Fuzzy analytical hierarchy process for evaluating and selecting a vendor in a supply chain model. Int. J. Adv. Manuf. Technol. 29, 826–835.

Olugu, E.U., Wong, K.Y., Shaharoun, A.M., 2011. Development of key performance measures for the automobile green supply chain. Resour. Conserv. Recycl. 55, 567–579.

Pi, W.-N., Low, C., 2006. Supplier evaluation and selection via Taguchi loss functions and an AHP. Int. J. Adv. Manuf. Technol. 27, 625–630.

Pophali, G.R., Chelani, A.B., Dhodapkar, R.S., 2011. Optimal selection of full scale tannery effluent treatment alternative using integrated AHP and GRA approach. Expert Syst. Appl. 38, 10889–10895.

Rao, P., 2002. Greening the supply chain: a new initiative in South East Asia. Int. J. Oper. Prod. Manag. 22, 632–655.

Saaty, T.L., 1980. The Analytic Hierarchy Process. McGraw-Hill, Columbus.

Saaty, T.L., 1996. Decision Making with Dependence and Feedback: The Analytic Network Process. RWS Publications, Pittsburgh.

Saaty, T.L., Sagir, M., 2009. An essay on rank preservation and reversal. Math. Comput. Model. 49, 1230–1243.

Saaty, T.L., Takizawa, M., 1986. Dependence and independence: from linear hierarchies to nonlinear networks. Eur. J. Oper. Res. 26, 229–237.

Saaty, T.L., Vargas, L.G., 1984. The legitimacy of rank reversal. Omega 12, 513–516.

Saaty, T.L., Vargas, L.G., 1993. Experiments on rank preservation and reversal in relative measurement. Math. Comput. Model. 17, 13–18.

Saaty, T.L., Varges, L.G., 2006. Decision Making With the Analytic Network Process. Springer, Pittsburgh, PA, USA.

Sarkis, J., 1998. Evaluating environmentally conscious business practices. Eur. J. Oper. Res. 107, 159–174.

Sarkis, J., 1999. A methodological framework for evaluating environmentally conscious manufacturing programs. Comput. Ind. Eng. 36, 793–810.

Sarkis, J., 2003. A strategic decision framework for green supply chain management. J. Clean. Prod. 11, 397–409.

Sarkis, J., 2006. Greening the Supply Chain. Springer, Berlin.

Sarkis, J., Talluri, S., 2002. A model for strategic supplier selection. J. Supply Chain Manag. 38, 18–28.

Seuring, S., Müller, M., 2008. From a literature review to a conceptual framework for sustainable supply chain management. J. Clean. Prod. 16, 1699–1710.

Shen, L., Olfat, L., Govindan, K., Khodaverdi, R., Diabat, A., 2013. A fuzzy multi criteria approach for evaluating green supplier's performance in green supply chain with linguistic preferences. Resour. Conserv. Recycl. 74, 170–179.

Shih, H.-S., Shyur, H.-J., Lee, E.S., 2007. An extension of TOPSIS for group decision making. Math. Comput. Model. 45, 801–813.

Simpson, P.M., Siguaw, J.A., White, S.C., 2002. Measuring the performance of suppliers: an analysis of evaluation processes. J. Supply Chain Manag. 38, 29–41.

Srivastava, S.K., 2007. Green supply-chain management: a state-of-the-art literature review. Int. J. Manag. Rev. 9, 53–80.

Talluri, S., 2002. A buyer-seller game model for selection and negotiation of purchasing bids. Eur. J. Oper. Res. 143, 171–180.

Tseng, M.-L., 2010. Using linguistic preferences and Grey relational analysis to evaluate the environmental knowledge management capacity. Expert Syst. Appl. 37, 70–81.

Warfield, J.N., 1974. Developing interconnection matrices in structural modeling. IEEE Trans. Syst. Man Cybern. 4, 81–87.

Wei, G.-W., 2010. GRA method for multiple attribute decision making with incomplete weight information in intuitionistic fuzzy setting. Knowl.-Based Syst. 23, 243–247.

Wu, H.-H., 2002. A comparative study of using Grey relational analysis in multiple attribute decision making problems. Qual. Eng. 15, 209–217.

Xu, G., Yang, Y.-p., Lu, S.-y., Li, L., Song, X., 2011. Comprehensive evaluation of coal-fired power plants based on grey relational analysis and analytic hierarchy process. Energy Policy 39, 2343–2351.

Xu, L., Kumar, D.T., Shankar, K.M., Kannan, D., Chen, G., 2013. Analyzing criteria and sub-criteria for the corporate social responsibility-based supplier selection process using AHP. Int. J. Adv. Manuf. Technol. 68, 907–916.

Yang, C.-C., Chen, B.-S., 2006. Supplier selection using combined analytical hierarchy process and Grey relational analysis. J. Manuf. Technol. Manag. 17, 926–941.

Yang, J.L., Chiu, H.N., Tzeng, G.-H., Yeh, R.H., 2008. Vendor selection by integrated fuzzy MCDM techniques with independent and interdependent relationships. Inf. Sci. 178, 4166–4183.

Yücenur, G.N., Vayvay, Ö., Demirel, N., 2011. Supplier selection problem in global supply chains by AHP and ANP approaches under fuzzy environment. Int. J. Adv. Manuf. Technol. 56, 823–833.

Zadeh, L.A., 1965. Fuzzy sets. J. Inf. Control 8, 338–353.

Zhang, J., Wu, D., Olson, D.L., 2005. The method of Grey related analysis to multiple attribute decision making problems with interval numbers. Math. Comput. Model. 42, 991–998.

Zhang, S.-f., Liu, S.-Y., Zhai, R.-h, 2011. An extended GRA method for MCDM with interval-valued triangular fuzzy assessments and unknown weights. Comput. Ind. Eng. 61, 1336–1341.

Zhu, Q., Sarkis, J., 2004. Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises. J. Oper. Manag. 22, 265–289.

Zhu, Q., Sarkis, J., Lai, K.-h, 2011. An institutional theoretic investigation on the links between internationalization of Chinese manufacturers and their environmental supply chain management. Resour. Conserv. Recycl. 55, 623–630.