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Developing a novel Grey integrated multi-criteria approach for enhancing the supplier selection procedure: A real-world case of Textile Company

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A B S T R A C T

Supplier selection is one of the most essential activities in purchase management and plays a crucial role in the production phase. Supplier selection as a vital step of supply chain management is a multi-criteria decision-making issue. For any organization, the process of selecting the best supplier holds variable multilayered complications involving quantitative and qualitative criteria. This paper tackles the supplier selection problem in a Turkish Textile Company. The present study carries out a novel grey integrated multi-criteria approach for enhancing the supplier procedure within Textile Company with the help of the grey analytical hierarchy process G-AHP model for weighting the set of criteria, and the grey weighted aggregated sum product assessment WASPAS-G model for prioritizing the suppliers. The study starts with reviewing the previous works of multi-criteria decision-making MCDM methods and the list of existing criteria evaluation in supplier selection. Then, the range of criteria is selected based on the company requirements and the experts' interview. In the case study, the consistency rate of the models is tested in order to verify the quality of experts' judgments. The final results affirm that Grey integrated approach could be efficient and far more precise than the existing models for overcoming the supplier selection and evaluation obstacles in the supply chain management.

1. Introduction

During the last decade, many organizations in the industrial area have faced a sharp competition due to the fact of globalization which has pushed them to choose the outsourcing strategy as a right solution to produce products at minimal cost. This strategy has participated in controlling the costs of sourced raw materials and products that are very often qualified to cover organization requirements and increase at the same time their competitiveness in the market (Steven et al., 2014). Currently, many organizations heavily rely on outsourcing trends and have become more dependent on suppliers to achieve their business tasks. Consequently, outsourcing in developing countries may have entailed some certain side-effects, e.g. the procedure of treatment with the suppliers has become more complex and the supply chain foundations turned into fragments, which would undoubtedly impact on the products quality and the organization's performance (Steven et al., 2014). In fact, the supply chain and

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suppliers performance have become more serious for the organizations' goals achievement (Handfield et al., 2002). In other words, the recent business world is no longer seen as a competition among organizations but among the organizations' suppliers as well (Lambert & Cooper 2000; Li et al., 2006; Bai & Sarkis 2014; Amid et al., 2009). In addition, supplier selection and evaluation process is considered as a crucial success factor and serious strategic decision-making issue that participate in enforcing the partnerships in supply chain (Chen & Paulraj, 2004). In other words, the supplier selection is considered as one of the most valuable problems for building a cornerstone in the supply chain management. The core objective of the supplier selection procedure is to reduce the risks and increase the value of relationships between organizations and suppliers as maximum as possible (Monczka et al., 1998). Recently, the most common goal of supplier selection is to designate the most appropriate supplier with the highest capabilities in delivering high-quality products and/or services at an affordable cost (Beşkese & Şakra, 2010). In essential, previous works have developed various models for supplier selection and evaluation process with regard to decision-making techniques (Boer et al., 1998; Lee et al., 2001).

However, these adopted techniques such as MCDM techniques are not sufficient and able to solve the complexity of nowadays organizations' purchasing strategies (Boer et al., 1998). As a consequence, the current supply chain has become far complex and ramified where disturbance can come at any time (Christopher, 2004). Previous researches have developed numerous studies in this domain that generally involve the adoption of the practical approaches and the application of a broader range of methodologies especially mathematical analytical (MA) models. Therefore, various MCDM methods have been formulated in order to re-arrange and support difficult decisions such as supplier selection (Wu et al., 2010). The procedure for selecting and evaluating the most potential supplier encompasses a broader set of external and internal influencing indicators (Kumar et al., 2014), this range takes the qualitative and quantitative selection and evaluation criteria into account (Sarkis & Talluri 2002), and holds out the variety of suppliers crosswise the supply chain (Bai & Sarkis 2010). Nowadays, selecting the most appropriate supplier not only relies on investigating some price list but, also it also relies on a broader range of criteria such as quality, delivery, technological capability, technical support. Then, the organization's internal or external aspects could be weighted based on its requirements, priorities, and long-term economic strategies. The designation of the criteria and the function of each defined criterion change from field to field. For this reason, organizations from different areas ought to embrace a strategic approach to facilitate the management of suppliers' partnership and prevent "one-size-fits-all" approach for supplier partnership management (Gurler AGI, 2007; Yilmaz O et al., 2011; Sagar MK et al., 2012).

Adopting a managerial approach that relies on more than one supplier can reduce the risk of production or service disruptions. The key challenge herein is not only to identify the main role of the supplier, but rather develop new approaches and methodologies to highlight supplier selections problems and solve the significant complexity within the supply chain. The vagueness and uncertainty are the certain sides of information specifically when the assessment procedure is handled by human judgment (Ghorabee et al., 2017). According to the tackled theory, as presented in section 2, the prior studies have mostly focused on the Fuzzy set theory or Hybrid theory and few limited works have taken Grey set theory into consideration in solving supplier section and evaluation problems. The core contribution of the present study is to present a novel grey integrated approach, which consists of G-AHP to identify the weightiness of criteria and WASPAS-G to classify the suppliers, to handle uncertainty in the supplier selection and evaluation procedure. Afterwards, a case study of Turkish Textile Company will be investigated to verify the constructed model and to show the feasibility of the suggested techniques. The present paper is structured as follows: Section 2 highlights the prior works on MCDM methods and mathematical models used for overcoming the obstacles faced throughout the process of selecting the convenient supplier. Section 3 underpins the development of a novel integrated model with the use of G-AHP and WASPAS-G techniques. Section 4 comprises the application and the verification of the constructed model in a case study of Textile Company. Section 5 presents the final results and discussions for future researches. Section 5 also underlines the practicability and reliability of the new approach. Section 6 concludes the present work and proposes some valuable recommendations for future researches.

2. Literature review

In this section, the literature review is mainly divided into two sections. First, the set of criteria defined by previous works will be reviewed. Then, the appropriate criteria in weighing and prioritizing suppliers for the present work will be outlined. Second, some of the MCDM methods and other mathematical models investigated in previous works for overcoming the problem of supplier selection will be also highlighted.

2.1 Supplier evaluation criteria assignment

Successfully performing the supplier selection strategy in the supply chain, researchers have to take into consideration a wide range of criteria. In other words, the selection of accurate criteria represents a basic step in the decision-making procedure for assessing and prioritizing suppliers (Buyukozkan & Cifci 2011). Weber et al. (1991) stated that the price is an essential indicator in decision making for evaluating end selecting the right supplier. Ho et al. (2010) declared that the basic set of criteria for selecting the resilient supplier entails price, quality, and delivery. While Chang et al. (2011) conducted a research that encompasses ten essential criteria which paid, later on, attention by numerous researchers from different fields of study. This set of criteria is as follows: 'quality, delivery reliability, lead time, cost, capacity, flexibility, technology capability, environmental control, service level, and reduction on demand'. However, this range of criteria can vary from one study to another. In the present work, the range of criteria will be selected and designated based on the supplier selection strategy requirements within the textile industry. The present study range of criteria encompasses quality, cost, technological capability, technical support, delivery, flexibility, supplier reputation, and discount opportunities.

Table 1
Summary of supplier selection criteria in prior researches

Authors	Associated criteria
Sen et al., 2009	Quality, Socio-economic, and technology
Luo et al., 2009	Resource and financial quality, and management
Kahraman et al., 2010	Service and product performance, and cost
Guneri et al., 2011	Quality, delivery, supplier relationship, problem-solving capability, and cost
Razaei et al., 2013	Supplier relationship, and exchange elements
Arikan et al., 2013	Quality, price, delivery, and capacity
Kumar Kar et al., 2014	Price, technology, financial management, delivery, E-transaction ability, and service product quality
Deng et al., 2014	Quality, risk factors, supplier's benefits, and service performance
Ulutas et al., 2016	Cost, financial position, delivery, flexibility, quality, technology, compliance with sectorial price, reputation, and communication issues
The present paper	Quality, cost, technological capability, technical support, delivery, flexibility, supplier reputation, and discount opportunities

2.2 Review of prior works based on MCDM techniques in supplier selection

During the last two decades, multi-criteria decision-making MCDM methods have become one of the most valuable approaches applied in the different research areas (Jato-Espino et al., 2014). During this period, numerous models have been developed and reformulated in order to overcome the complexity discovered through the process of the supplier selection but, the majority of researchers have mostly focused on decision-making methods, with complex mathematical models, to resolve the supplier selection problem. In literature, however, various studies have tackled and proposed different techniques in a variety of ways for overcoming the issue of complexity in supplier selections. Table 1 highlights and summarizes the most important methods adopted by several researchers for supplier selection and evaluation, respectively.

Table 2

Review of prior researches in applying variable models for supplier selection

Authors	Methods	Article Abstract
Önüt et al., 2009	Fuzzy set, MCDM, and TOPSIS ANP	Proposed a supplier selection approach that relies on the application of TOPSIS and ANP to overcome the obstacle of selecting the right supplier in the telecommunication industry.
Amid et al., 2009	Fuzzy MCDM	Presented a weighted fuzzy multi-objective approach to support the supplier selection and evaluation under fuzzy environment.
Wang et al., 2009	MCDM, Fuzzy TOPSIS, and Fuzzy FAHP	Developed an approach that combines both Fuzzy TOPSIS and Fuzzy AHP to evaluate and select the right.
Boran et al., 2009	MCDM, TOPSIS, and Fuzzy set theory	Presented an intuitionistic fuzzy approach with the use of TOPSIS technique to support the selection of the right supplier.
Sanayei et al., 2010	Fuzzy set, and VIKOR	Developed a hierarchy MCDM approach that relies on Fuzzy VIKOR technique as a convenient model to deal with complexity in supplier selection strategy.
Shemshadi et al., 2011	Fuzzy logic, VIKOR, Entropy measure, and MCDM.	Developed a fuzzy VIKOR method in order to overcome the MCDM criteria conflicts problems. Shannon entropy is used to fix the subjectivity of weights of judgements.
Deng et al., 2011	MCDM, Dempster-Shafer theory, Fuzzy sets theory and TOPSIS	Presented a combination of FST and DST as an ideal and flexible solution for an uncertain environment. TOPSIS is then proposed to solve the problem in supplier selection.
Lin et al., 2011	Enterprise resource planning (ERP), ANP, TOPSIS, and Linear programming (LP).	Applied ERP and LP methods in order to specify the strength and weakness in the supplier selection and evaluation procedure. TOPSIS and ANP are employed to compute the weights and rank the suppliers.
Buyukozkan et al., 2012	Fuzzy ANP, DEMATEL, and TOPSIS.	Integrated a new hybrid fuzzy MCDM approach based on the use of DEMATEL, ANP and TOPSIS are then proposed to evaluate the green suppliers.
Haldar et al., 2012	AHP, TOPSIS, subjective factor measures (SFM), and objective factor measure (OFM).	Presented a hybrid approach that incorporates MCDM techniques together to help decision makers to designate the right supplier. AHP-QFD is used to reveal the critical criteria. Afterwards, SFM and OFM are used to define the factor affecting supplier selection.
Nilesh et al., 2012	Fuzzy set theory AHP, and ANP.	Proposed a detailed review of supplier selection and projected the practicability of MCDM techniques for futures researcher and studied the feasibility of these techniques in the current published literature.
Khodadadzadeh et al., 2013	MCDM, Data development analysis (DEA), TOPSIS, and AHP	Proposed a survey of employing different form of MCDM techniques for supplier selection and evaluation such as DEA, TOPSIS, and AHP.
Ghorbani et al., 2013	Fuzzy TOPSIS, and Kano model.	Formulated a new approach that integrates Fuzzy TOPSIS and Kano MODEL. This study has taken the ambiguity of people judgement into consideration to solve the issue of supplier selection.
Dursun et al., 2013	Quality function deployment (QFD), MCDM, and Fuzzy weighted average (FWA).	Developed a fuzzy model that uses QFD for the supplier selection process. The FWA method is utilized to turn the imprecise information into linguistic variables.
Memon et al., 2015	Grey systems theory, and uncertainty theory.	Presented a framework of Combined grey systems theory and uncertainty theory for minimizing the risk of purchase quantity associated with suppliers.
Ertugrul et al., 2015	Fuzzy set theory (FST) MCDM, and QFD	Proposed a framework proposed to use a combination of ordered weighted averaging (OWA) and Fuzzy set theory.
Awasthi et al., 2016	Fuzzy set theory (FST) NGT, and VIKOR.	Formulated Fuzzy NGT to evaluate the green supplier and Fuzzy VIKOR is then applied to rank and propose the most appropriate green supplier.
Nallusamy et al., 2016	Fuzzy AHP, AN, and FL	Proposed the linear weighting techniques to solve the complexity problem faced throughout the process the supplier selection.
Rezaeisaray et al., 2016	MCDM, DEMATEL, FANP, and DEA	Proposed a novel hybrid model to select and evaluate the most resilient supplier based on the utilization of DEMATEL for structuring the criteria. FANP and DEA are used to weight the criteria.
Chen et al., 2016	Fuzzy AHP, and TOPSIS	Presented an appropriate model for green supplier selection comprising environmental and economic criteria in supplier selection procedure.
Yazdani et al., 2016	MCDM, SWARA, QFD, and WASPAS	Presented an integrated frame for formulating an effective supplier selection approach in the supply chain with the use of SWARA, QFD and WASPAS.
J Rezaei et al., 2016	MCDM, and BWM	Applied a methodology for selecting the most potential supplier within a food supply chain background with the use of the best and worst method.
Wan et al., 2017	MCDM, II IT-ELECTRE II, and TL-ANP	Investigated MCDM problems with regard to two-level criteria and Presented a new hybrid approach combining TL-ANP and IT-ELECTRE II to select the most appropriate supplier in the supply chain.
Gupta et al., 2017	BWM, and Fuzzy TOPSIS	Presented a methodology that relies on the Fuzzy TOPSIS and BWM to rank and weight the criteria of green suppliers in the supply chain. Sensitivity analysis is also tackled to check the strength of the constructed framework.
Hamdan et al., 2017	MCDM, multi-objective optimization approach, AHP, and TOPSIS.	Presented a multi-objective optimization approach that combines fuzzy AHP and Fuzzy TOPSIS to opt the most potential supplier.
Parkouhi et al., 2017	Fuzzy ANP and Grey VIKOR.	Used Fuzzy ANP to determine the potential supplier and Grey VIKOR were applied to specify the level of importance of the resilient supplier.
Buyukozkan et al., 2017	IFAD and IF-AHP.	Integrated an approach used to overcome the vagueness and handle the ambiguity of the decision process in supplier selection and evaluation.
Bakeshlou et al., 2017	MCDM, Fuzzy ANP, and Fuzzy DEMATEL, MOLP	Presented an approach that relies on Fuzzy ANP and DEMATEL to perceive the interrelation between criteria for green suppliers.
Yazdani et al., 2017	DEMATEL, quality function deployment (QFD), and COPRAS.	Addressed an approach that combines QFD with DEMATEL to construct a fundamental relationship matrix to determine the nature of the relationship between green supplier selection criteria.
Goh et al., 2018	MCDM, Fuzzy AHP, and Fuzzy TOPSIS.	Formulated AHP and TOPSIS model with the help of Fuzzy set theory to support the selection of healthcare suppliers.
Jiang et al., 2018	MCDM, DEMATEL, ANP, and Grey DANP.	Developed a grey-DANP model to decrease the problem coming from the pairwise comparison in supplier selection criteria.
Yousaf Ali et al., 2018	MCDM, ANP, and TOPSIS.	Used an approach technically applied to assign variable range of criteria for supplier selection in the oil refinery.
Quan et al., 2018	MCDM, MULTIMOORA, and LINMAP.	Proposed the development of hybrid MCDM approach to objectively evaluate the criteria for green supplier selection and handle the uncertainty in data.
Liu et al., 2018	Game theory, DEMATEL, MCDM, and ANP	Presented a combination of different methods used to limit the fuzziness and ambiguity in supplier selection process.
Haeri et al., 2019	Grey relational analysis, BWM, and Fuzzy grey cognitive maps	Proposed a grey-based model for choosing the most convenient green supplier with the help of Fuzzy techniques.
Mohamed et al., 2019	Fuzzy FMOO, Fuzzy AHP, and Fuzzy TOPSIS.	Presented a hybrid MCDM to resolve the issue of multiple uncertainties in supplier selection procedure by taken the economic, environmental and social criteria into consideration.
Deshmukh et al., 2019	MCDM and Fuzzy FAHP.	Developed a Fuzzy FAHP model to select and evaluate the most appropriate green supplier.
Lieu et al., 2019	MCDM, BWM, and AQM	Adopted the best worst method and alternative queuing method with MCDM technique to solve rank the supplier.
Bai et al., 2019	Grey- BWM, and Grey-TODIM	Proposed Grey approach to determine social sustainability attribute weights and ranking the suppliers.

In theory, only a few researchers have tackled the Grey systems theory to support MCDM techniques in supplier selection. Therefore, it is noticed that during the last decades the Grey systems theory has been recognized by numerous researchers as a successful approach due to the results have been harvested in several research fields such as economy (Julong, 1984), industry (Biao, 1986) management (Julong, 1986c), etc.

The core objective of the present study is to adopt a Grey systems theory to support MCDM techniques and overcome the complexity highlighted during the process of selecting the most resilient supplier. Consequently, the main role of the developed Grey integrated model herein is to handle the vagueness revealed in the supplier selection procedure. The Grey systems theory used within this study holds variable advantages (e.g. Li et al., 2007; Tseng, 2009; Bai et al., 2010; Saeedpoor et al., 2012; Dou et al., 2014; Memon et al., 2015; Xia et al., 2015):

- the grey systems theory provides reasonable results employing a moderate amount of data compared with other statistical modelling methods and techniques;
- it is considered as one of the improved theories in terms of exact and completed information;
- it is a solid theory towards the noise and shortage of information modelling;
- the theoretical contribution has proved that a grey-based method can accomplish remarkable performance features;
- the grey systems theory offers '*no parametric, a relatively resilient, distribution assumptions, and the best way to turn fuzziness into a problem*';
- it is better than fuzzy set theory in term of the fuzziness conditions;
- it does not require any kind of fuzzy robust membership tasks;
- the advantages of this method over fuzzy set theory are that it is developed in case of tacky information and slight samples; and
- due to poor incomplete information and uncertainty, the grey systems theory plays a major role in several decision-making problems.

3. Developed model: a novel Grey integrated approach of AHP and WASPAS

The multi-criteria decision-making (MCDM) techniques are generally employed to measure the alternatives for future decisions. It is considered as one of the most useful methods in operations research that entails a broader set of techniques that are appropriate to overcome the complexity of supplier evaluation and selection. In this paper, a novel Grey integrated model of AHP and WASPAS is developed to determine the best supplier for a Turkish textile company.

3.1 The Grey Analytic Hierarchy (G-AHP) model for weighting the criteria of suppliers

The G-AHP, which is employed to define the weights of criteria, consists of three main strides that could be displayed as follows (Ulutaş, 2016);

1st stride: Decision makers assign linguistic weights as indicated in Table 3, and then these linguistic weights are transformed into grey weights by utilising Table 3. After this process, the grey comparison matrix ($\otimes$ Z) is structured as follows:

$$\otimes \mathrm{Z} = (\otimes z_{ij})_{n\times n} \tag{1}$$

where

$$\otimes z_{ij} = \left[\underline{z_{ij}}, \overline{z_{ij}}\right] \text{ and } z_{ij}^{-1} = \left[\frac{1}{\overline{z_{ij}}}, \frac{1}{\underline{z_{ij}}}\right] \tag{2}$$

In Eq. (2), $\underline{z_{ij}}$ and $\overline{z_{ij}}$ indicate the minimum and the maximum values of $\otimes z_{ij}$ correspondingly.

Table 3
Linguistic terms and their Grey Weights

Linguistic Weights	Grey Weights
Absolute Significant (AS)	[7 , 9]
More Significant (MS)	[5 , 7]
Significant (S)	[3 , 5]
Moderately Significant (MS)	[1 , 3]
Equal Significant (ES)	[1 , 1]

2nd stride: First, grey values are translated into crisp values with the aid of Eq. (3). Then, the consistency of the grey matrix is analysed with Eq. (4) and Eq. (5) (Saaty, 1990). If CR is < 0.1 the study directly moves to step 3.

$$z_{ij} = \frac{1}{2} \times \left(\underline{z_{ij}} + \overline{z_{ij}}\right) \quad (3)$$

$$CI = \frac{(\nabla_{max} - n)}{(n-1)} \quad (4)$$

$$CR = \left(\frac{CI}{RI}\right) \quad (5)$$

3rd stride: By applying Eq. (6) (the row sums of$\otimes$ Z) and by also using Eq. (8) and Eq. (9), the grey row sums ($\otimes Y_i$) are normalized to define the grey weight ($\otimes w_i$) of each criterion. These values are afterwards transferred into WASPAS-G.

$$\otimes Y_i = \sum_{j=1}^{n} \left[\underline{z_{ij}}, \overline{z_{ij}}\right] \quad (6)$$

$$\otimes Y_i = \left[\underline{Y_i}, \overline{Y_i}\right] \quad (7)$$

$$\underline{Y_i^*} = \left[\frac{2 \times \underline{Y_i}}{\sum_{i=1}^{n} \underline{Y_i} + \sum_{i=1}^{n} \overline{Y_i}}\right] \quad (8)$$

$$\overline{Y_i^*} = \left[\frac{2 \times \overline{Y_i}}{\sum_{i=1}^{n} \underline{Y_i} + \sum_{i=1}^{n} \overline{Y_i}}\right] \quad (9)$$

$$\otimes w_i = \left[\underline{Y_i^*}, \overline{Y_i^*}\right] = \left[\underline{w_i}, \overline{w_i}\right] \quad (10)$$

3.2 The Grey weighted aggregated sum product assessment(WASPAS-G) model for prioritising the criteria of suppliers

According to Zavadskas et al. (2015), the WASPAS-G model normally entails four main steps. The present study adopts the process of four steps as well to prioritise the appropriate criteria in supplier selection and evaluation procedure. These essential strides are presented as follows;

1st stride: A grey decision matrix is structured with regard to the preferences of decision makers. First, they assign linguistic values as shown in Table 4. Then, these defined values are converted into grey values in order to construct the grey decision matrix ($\otimes T$).

$$\otimes T = \begin{bmatrix} \otimes t_{11} & \cdots & \otimes t_{1i} & \cdots & \otimes t_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \otimes t_{v1} & \cdots & \otimes t_{vi} & \cdots & \otimes t_{vn} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \otimes t_{m1} & \cdots & \otimes t_{mi} & \cdots & \otimes t_{mn} \end{bmatrix} \quad (11)$$

Table 4
Linguistic terms and an their Grey Values

Linguistic Values	Grey Values
Very Poor (VP)	[0 , 0.20]
Poor (P)	[0.10 , 0.30]
Medium Poor (MP)	[0.20 , 0.40]
Fair (F)	[0.35 , 0.65]
Medium Good (MG)	[0.60 , 0.80]
Good (G)	[0.70 , 0.90]
Very Good (VG)	[0.80 , 1]

Source: Adapted from Zavadskas et al. (2015)

2nd stride: Each value in the grey decision matrix ($\otimes T$) is normalized by using Eq. (12) (beneficial criteria) and Eq. (13) (non-beneficial criteria). In Eqs. (12-13), $\otimes t'_{vi}$ denotes the grey normalized value.

$$\otimes t'_{vi} = \frac{\otimes t_{vi}}{max_v \otimes t_{vi}} = \left[\frac{\underline{t_{vi}}}{max_v \overline{t_{vi}}}, \frac{\overline{t_{vi}}}{max_v \overline{t_{vi}}}\right] \tag{12}$$

where

$$\otimes t'_{vi} = \frac{min_v \otimes t_{vi}}{\otimes t_{vi}} = \left[\frac{min_v \underline{t_{vi}}}{\overline{t_{vi}}}, \frac{min_v \underline{t_{vi}}}{\underline{t_{vi}}}\right] \tag{13}$$

3rd stride: The grey weighted sum model ($\otimes B_v = \left(\underline{B_v}, \overline{B_v}\right)$) and the grey weighted product model ($\otimes K_v = \left(\underline{K_v}, \overline{K_v}\right)$) are obtained by using Eq. (14) and Eq. (15) respectively. Then, these grey values are transformed into crisp values (B_v , K_v) by setting Eq. (16) and Eq. (17), respectively.

$$\otimes B_v = \sum_{i=1}^{n} \otimes t'_{vi} \times \otimes w_i = \left[\sum_{i=1}^{n} \underline{t'_{vi}} \times \underline{w_i}, \sum_{i=1}^{n} \overline{t'_{vi}} \times \overline{w_i}\right] \tag{14}$$

$$\otimes K_v = \prod_{i=1}^{n} (\otimes t')^{\otimes w_i} = \left[\prod_{i=1}^{n} \left(\underline{t'_{vi}}\right)^{\underline{w_i}}, \prod_{i=1}^{n} \left(\overline{t'_{vi}}\right)^{\overline{w_i}}\right] \tag{15}$$

$$B_v = \frac{\underline{B_v} + \overline{B_v}}{2} \tag{16}$$

$$K_v = \frac{\underline{K_v} + \overline{K_v}}{2} \tag{17}$$

4th stride: The final score for each supplier can be achieved by using Eq. (18). The A_v herein denotes the ultimate value of vth supplier. Furthermore, the supplier that encompasses the highest final score is selected as the most appropriate supplier in the supply chain.

$$A_v = \gamma B_v + (1 - \gamma) K_v \tag{18}$$

where

$$\gamma = 0.5 \frac{\sum_{v=1}^{m} K_v}{\sum_{v=1}^{m} B_v} \tag{19}$$

4. Real world case study

In the present paper, the development of the grey integrated model is applied and verified within a Turkish textile company that normally belongs to the garment sector in Turkey. A very qualified team, involving the factory manager, deputy director, and the industrial engineer, was consulted. As mentioned above, the present study focuses on eight main criteria with regard to the textile company supplier selection strategy requirements. However, this range of criteria is presented as follows:

- Quality **(Q)**,
- Cost **(C)**,
- Technological Capability **(TC)**,
- Technical Support **(TS)**,
- Delivery **(D)**,
- Flexibility **(F)**,
- Supplier Reputation **(SR)**, and
- Discount Opportunities **(DO)**.

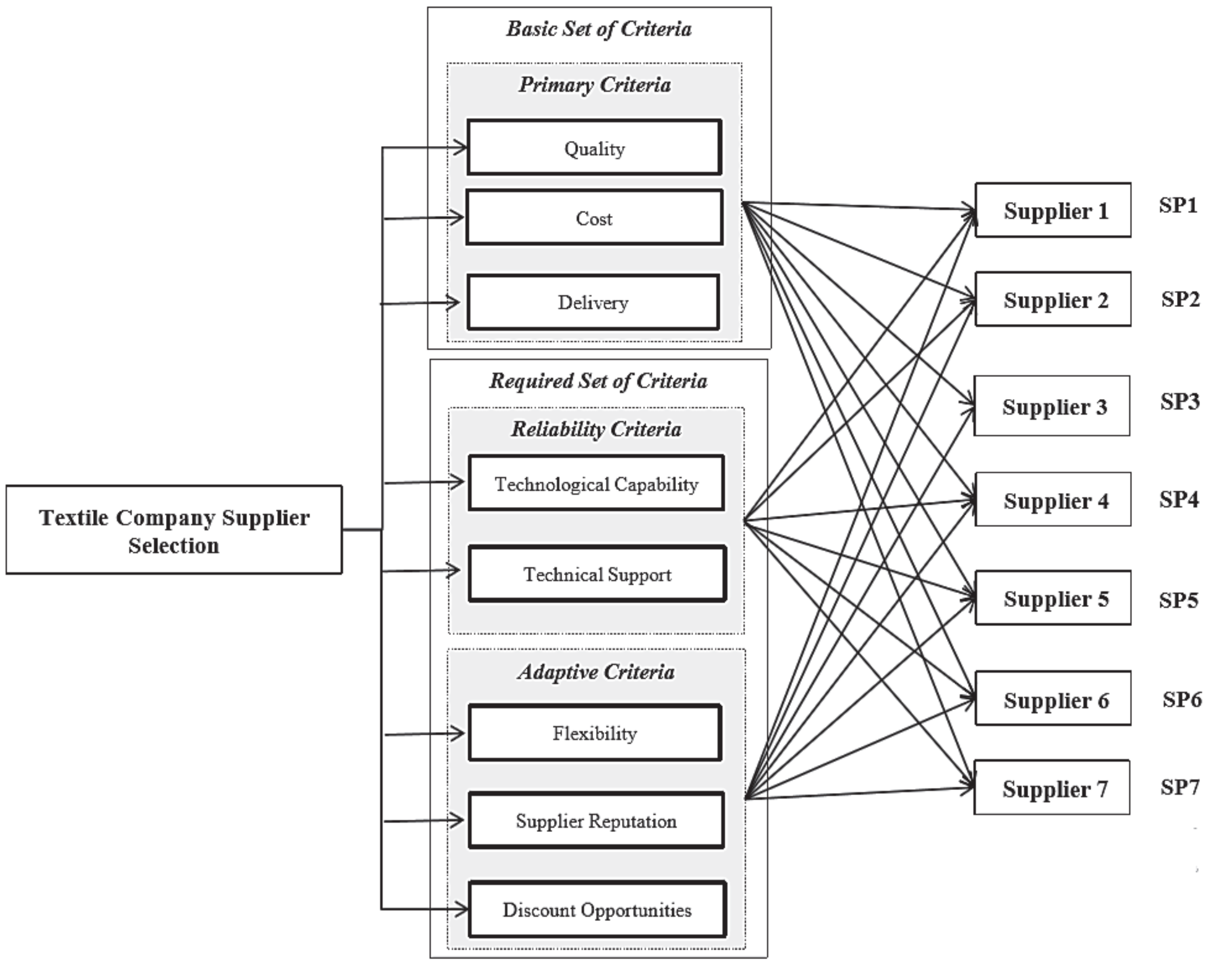

Fig. 1. Set of criteria for selecting the right supplier in Turkish Textile Company

The grey comparison matrix is constructed with the support and the assessments of this qualified team. The grey comparison matrix is illustrated in detail in Table 5.

Table 5
Grey Constructed Comparison Matrix

	Criteria			
Criteria	Q	C	TC	TS
Q	[1 , 1]	[1 , 3]	[3 , 5]	[3 , 5]
C	[0.333 , 1]	[1 , 1]	[3 , 5]	[3 , 5]
TC	[0.2, 0.333]	[0.2, 0.333]	[1 , 1]	[3 , 5]
TS	[0.2, 0.333]	[0.2, 0.333]	[0.2, 0.333]	[1 , 1]
D	[1 , 1]	[1 , 1]	[3 , 5]	[3 , 5]
F	[0.2, 0.333]	[0.2, 0.333]	[1 , 1]	[0.333 , 1]
SR	[0.2, 0.333]	[0.2, 0.333]	[0.2, 0.333]	[0.333 , 1]
DO	[0.2, 0.333]	[0.2, 0.333]	[0.2, 0.333]	[1 , 1]

	Criteria			
Criteria	D	F	SR	DO
Q	[1 , 1]	[3 , 5]	[3 , 5]	[3 , 5]
C	[1 , 1]	[3 , 5]	[3 , 5]	[3 , 5]
TC	[0.2, 0.333]	[1 , 1]	[3 , 5]	[3 , 5]
TS	[0.2, 0.333]	[1 , 3]	[1 , 3]	[1 , 1]
D	[1 , 1]	[3 , 5]	[5 , 7]	[3 , 5]
F	[0.2, 0.333]	[1 , 1]	[3 , 5]	[1 , 1]
SR	[0.143 , 0.2]	[0.2, 0.333]	[1 , 1]	[0.2, 0.333]
DO	[0.2, 0.333]	[1 , 1]	[3 , 5]	[1 , 1]

The row sums of the grey comparison matrix and the grey weights of criteria are shown in Table 6.

Table 6
The Results of G-AHP model

	Results	
Criteria	$\otimes Y_i$	$\otimes w_i$
Q	[18 , 30]	[0.159 , 0.265]
C	[17.333 , 28]	[0.153 , 0.247]
TC	[11.6 , 17.999]	[0.102 , 0.159]
TS	[4.8 , 9.332]	[0.042 , 0.082]
D	[20 , 30]	[0.177 , 0.265]
F	[6.933 , 9.999]	[0.061 , 0.088]
SR	[2.476 , 3.865]	[0.022 , 0.034]
DO	[6.8 , 9.332]	[0.060 , 0.082]

$\boldsymbol{CR}$ **=0.096 < 0.1**

After using G-AHP, the grey decision matrix, which is structured with regard to the preferences of decision makers, is explained in Table 7. The value of the consistency rate of G-AHP model is less than 0.1 which means that the collected data from the decision makers is feasible and reliable.

Table 7
Grey Constructed Decision Matrix

	Criteria			
Supplier	Q	C	TC	TS
SP1	[0.60 , 0.80]	[0.70 , 0.90]	[0.35 , 0.65]	[0.20 , 0.40]
SP1	[0.70 , 0.90]	[0.60 , 0.80]	[0.60 , 0.80]	[0.20 , 0.40]
SP3	[0.70 , 0.90]	[0.60 , 0.80]	[0.35 , 0.65]	[0.35 , 0.65]
SP4	[0.60 , 0.80]	[0.70 , 0.90]	[0.20 , 0.40]	[0.20 , 0.40]
SP5	[0.60 , 0.80]	[0.60 , 0.80]	[0.60 , 0.80]	[0.35 , 0.65]
SP6	[0.70 , 0.90]	[0.60 , 0.80]	[0.35 , 0.65]	[0.20 , 0.40]
SP7	[0.60 , 0.80]	[0.60 , 0.80]	[0.20 , 0.40]	[0.35 , 0.65]
	Criteria			
Supplier	D	F	SR	DO
SP1	[0.35 , 0.65]	[0.35 , 0.65]	[0.35 , 0.65]	[0.35 , 0.65]
SP2	[0.35 , 0.65]	[0.35 , 0.65]	[0.60 , 0.80]	[0.10 , 0.30]
SP3	[0.35 , 0.65]	[0.60 , 0.80]	[0.60 , 0.80]	[0.10 , 0.30]
SP4	[0.20 , 0.40]	[0.60 , 0.80]	[0.35 , 0.65]	[0.35 , 0.65]
SP5	[0.20 , 0.40]	[0.35 , 0.65]	[0.35 , 0.65]	[0.35 , 0.65]
SP6	[0.35 , 0.65]	[0.35 , 0.65]	[0.35 , 0.65]	[0.35 , 0.65]
SP7	[0.35 , 0.65]	[0.60 , 0.80]	[0.35 , 0.65]	[0.35 , 0.65]

Eq. (12) and Eq. (13) are integrated into the grey decision matrix in order to convert grey values, in the same matrix, into grey normalized values. These normalized values are given in Table 8.

Table 8
Grey Normalized Values

Supplier	Criteria Q	C	TC	TS
SP1	[0.667 , 0.889]	[0.667 , 0.857]	[0.438 , 0.813]	[0.308 , 0.615]
SP2	[0.778 , 1]	[0.750 , 1]	[0.750 , 1]	[0.308 , 0.615]
SP3	[0.778 , 1]	[0.750 , 1]	[0.438 , 0.813]	[0.538 , 1]
SP4	[0.667 , 0.889]	[0.667 , 0.857]	[0.250 , 0.500]	[0.308 , 0.615]
SP5	[0.667 , 0.889]	[0.750 , 1]	[0.750 , 1]	[0.538 , 1]
SP6	[0.778 , 1]	[0.750 , 1]	[0.438 , 0.813]	[0.308 , 0.615]
SP7	[0.667 , 0.889]	[0.750 , 1]	[0.250 , 0.500]	[0.538 , 1]
	Criteria			
Supplier	D	F	SR	DO
SP1	[0.538 , 1]	[0.438 , 0.813]	[0.438 , 0.813]	[0.538 , 1]
SP2	[0.538 , 1]	[0.438 , 0.813]	[0.750 , 1]	[0.154 , 0.462]
SP3	[0.538 , 1]	[0.750 , 1]	[0.750 , 1]	[0.154 , 0.462]
SP4	[0.308 , 0.615]	[0.750 , 1]	[0.438 , 0.813]	[0.538 , 1]
SP5	[0.308 , 0.615]	[0.438 , 0.813]	[0.438 , 0.813]	[0.538 , 1]
SP6	[0.538 , 1]	[0.438 , 0.813]	[0.438 , 0.813]	[0.538 , 1]
SP7	[0.538 , 1]	[0.750 , 1]	[0.438 , 0.813]	[0.538 , 1]

Eq. (14) is employed in this present work to compute the grey weighted sum model ($\otimes B_v$). This obtained grey value is consistently converted into crisp value (B_v) with the help of Eq. (16). Additionally, Eq. (15) is obviously used in this case to calculate the grey weighted product model ($\otimes K_v$). This attained grey value is also converted into crisp value (K_v) with the help of Eq. (17). Furthermore, the use of Eq. (18) leads the study to the final destination where the final score of each supplier revealed. Table 9 explains in details the outcomes of the constructed WASPAS-G model.

Table 9
Final results of the constructed Grey model

Suppliers	Results $\otimes B_v$	$\otimes K_v$	B_v
SP1	[0.430 , 1.074]	[0.621 , 0.846]	0.752
SP2	[0.476 , 1.131]	[0.643 , 0.885]	0.804
SP3	[0.473 , 1.149]	[0.644 , 0.908]	0.811
SP4	[0.389 , 0.939]	[0.549 , 0.701]	0.664
SP5	[0.444 , 1.069]	[0.620 , 0.831]	0.757
SP6	[0.460 , 1.139]	[0.648 , 0.906]	0.800
SP7	[0.452 , 1.108]	[0.632 , 0.862]	0.780
	Results		
Supplier	K_v	A_v	Ranks
SP1	0.734	0.743	**5**
SP2	0.764	0.785	**3**
SP3	**0.776**	**0.794**	**1**
SP4	0.625	0.645	**7**
SP5	0.726	0.742	**6**
SP6	0.777	0.789	**2**
SP7	0.747	0.764	**4**

Supplier 3 **(SP 3)** is presented to be the most appropriate alternative among the seven alternatives. According to the final results generated in Table 9, the relative closeness of the supplier 3 is high with values of 0.776 and 0.794. While the second appropriate alternative is the supplier 6 with values of and 0.777 and 0.789.

5. Results and discussions

From the model reliability perspective, the Grey AHP and Grey WASPAS model results reveal that supplier 3 is the appropriate supplier amidst other seven suppliers followed by the Turkish Textile Company. However, the model results also show that the supplier with the worst performance highlighted as supplier 4 as demonstrated in Table 9. The use of Grey AHP model in the present work provides constant criteria weighting while Grey WASPAS model generates suppliers (alternatives) rankings with regard to the company requirements. The Grey integrated model is able to offer precise information in very less complexity. In other words, the supplier selection and evaluation procedure are achieved in a limited number of steps and operations. From the academic perspective, the present study presents a Grey integrated model consisting of AHP-WASPAS for supplier selection and evaluation under an uncertain and non-quantitative environment. The main challenge addressed within this work is to assess all the risks and complexities found during the process of selecting the right supplier due to the ambiguity of the collected data in very less time. However, the final results affirm that this approach could be applied within other sectors and with the employment of a broader range of criteria and sub-criteria. Furthermore, the novel constructed grey integrated multi-criteria approach could be effective and useful for other future researches in the variable fields of study, due to its simplicity and applicability in a very short time, such as industry, military, medicine, biology, agriculture, ecology and so on.

6. Conclusion

This study has proposed a novel approach appropriate for Textile Company for selection of the most appropriate supplier in the supply chain in Turkey. The seven important suppliers and the eight essential criteria were examined in the context of overcoming the obstacle in selecting the resilient supplier to Textile Company. In addition, this paper has underlined the two main contributions: (1) Accordingly, it has revealed that there was a limited number of studies that combined the Grey systems theory approach with MCDM techniques, specifically G-AHP and WASPAS-G, to solve the problem of supplier selection and overcome the complexity of the procedure during the application in the supply chain. (2) Subsequently, this paper has developed a novel grey integrated multi-criteria approach that could be regarded as a convenient framework for any other future research with the application of an unlimited number of criteria especially when the decision-maker has limited access to data and is usually exposed to the fuzzy environment in the context of human judgments.

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