Service supply chain environmental performance evaluation using Grey based hybrid MCDM approach

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Abstract

Contribution of service supply chains to economic growth is significant and recent climate change issues expect services to be greener. The entire supply chain will be green if their suppliers adopt the requirements of the focal company and customers. Hence, it is essential that every organization constantly analyses and monitors the green performance of different members of the supply chains. Furthermore comprehensive studies have been carried out to identify criteria to evaluate green performance of manufacturing supply chain. However there is lack of studies to identify criteria and evaluate the performance of service supply chain. Service supply chain green performance evaluation necessitates methods to consider both qualitative and quantitative factors. Many conventional multi- criteria decision making (MCDM) methods have drawbacks such as inability to capture realistic fuzziness in decision making (human judgment), inadaptability to different levels of measurement, complexity in calculation and requirement of intricate details, which render them unsuitable for the task of environmental performance evaluation of service supply chains. In this paper, a grey based hybrid framework for evaluating the environmental performance of service supply chains is proposed by integrating grey based method with ELECTRE and VIKOR approaches. Two case studies were carried out to understand the effectiveness of criteria and method to evaluate environmental performance of service supply chains in a developing country context.

Keywords: service supply chain, environmental performance, grey, MCDM,

1. Introduction

Green supply chain management (GSCM) is an emerging organizational philosophy to achieve economic sustainability by reducing environmental risks and impacts with improved ecological efficiency of the focal companies and their partners (Diabat et al., 2013). Based on the study of Basu and Wright (2008), we define GSCM as a supply chain which adapts set of environmental practices to overcome regulatory issues and interventions from various stakeholders in order to minimize overall environmental disruptions. Firms worldwide are more concerned with environment due to severe pressures from regulatory authorities, customers and competitors (Georgiadis and Besiou, 2010). These pressures are due to climate change, diminishing raw material resources, overflowing waste sites, and increasing pollution levels. In recent years, GSCM initiatives are popular and widely used by firms to protect environment and to enhance their green image (Bose and Pal, 2012; Lin, 2013). Institutional pressure is an important motivator for the green adoption of advanced environmental management practices. Focal companies do not act alone but are interconnected which mandates all the members to adopt green practices (Seuring et al., 2008). Through GSCM, firms can select a wide variety of suppliers and leverage resources throughout the firm to eliminate the environmental impacts of supply chain activities (Tseng, 2010).

It is interesting to note that all organizations do not face the same pressure for GSCM adoption (Zhu and Sarkis, 2006). Different industry sectors in different parts of the world face various pressures. Xiao (2006) suggests five environmental pressures from the stakeholder point of view: (a) government as regulatory stakeholder, (b) media, (c) local resident as a community group, (d) contractors and clients, and (e) other stakeholders including related organization which can affect the company financially. Realizing that sustainability can drive the improvement of the company's bottom line through cost savings, improved market share, and stronger brand images, a growing number of firms have begun to take greening initiatives as their strategic weapons (Min and Kim, 2012).

The traditional end of the pipe approach only transforms pollutants from one form to another and does not eliminate them (Eltayeb et al., 2011). Unlike the traditional environmental management approach, however, the GSCM concept supposes complete responsibility of an organization towards its products and services from the extraction of raw materials up to final use and disposal. It represents the application of sound environmental management principles to all stages of a product's life cycle, including design, procurement, manufacturing, assembly, packaging, logistics, distribution, usage and final recycling to enhance an organization's competitive advantage (Handfield et al., 1997; Eltayeb et al., 2011). To improve their environmental performance, individual firms have implemented various kinds of environmental practices such as ISO14000 certification, cleaner production, environmental management systems and ecodesign. Recent studies suggests six GSCM dimensions such as green manufacturing and packaging, environmental participation, green marketing, green suppliers selection, green stock, and green eco design as potential ways to compete against rivals (Shang et al., 2010).

The successful and efficient functioning of an organization is greatly influenced by the degree of efficiency of performance of the supply chains the organization is employing in general and in particular the green performance of the members of the supply chains can have significant impact on the overall green performance of organizations. Hence it is absolutely essential that every organization constantly evaluates and monitors the environmental performance of the different member firms of the supply chains the organization is making use of. During recent years many researchers have investigated GSCM practices and performances in manufacturing sector (Zhu et al., 2007 a,b; De Britto et al., 2008; Zhu et al., 2008 a,b; Jain et al., 2009;

Bhattacharya et al., 2010; Georgiadis and Besiou, 2010; Diabat and Govindan, 2011; Kumaraswamy et al., 2011; Tseng, 2011; Tseng and Huang, 2011; Zarandi et al., 2011; Giminez et al., 2012; Hassini et al., 2012; Pirraglia and Saloni, 2012; Lin, 2013; Tseng and Chiu, 2013; Bhattacharya et al., 2014; Karsak and Dursun, 2014; Rezaei et al., 2014; Yu and Wong, 2014).

Few popular criteria used to evaluate green performance of suppliers are environment management system, GSCM capabilities, level of commitment to environment, degree of green supplier assessment, degree of green supplier collaboration and pollution control and prevention (Lee et al., 2009; Grisi et al., 2010; Large and Thomsen, 2011; Govindan et al., 2013). From the above studies it is obvious that criteria used to evaluate manufacturing sector have been discussed well in the literature. However, the criteria suitable to evaluate service supply chains are not well known.

In terms of methods, early studies proposed hybrid methods but most of them are related with fuzzy based method. Few of them are Noci (1997); Zhang et al. (2003); Awasthi et al. (2010). However few other studies used other methods such as DEA (Kumar and Jain, 2010; Wen and Chi, 2010; Kuo and Lin, 2011; Mirhedayatian et al., 2014). In terms of developing country context, few attempts were made to identify the status quo of environmental aspects such as awareness, sharing environment knowledge and recognizing the importance of environmental performance over economic performances of supply chains (Govindan et al., 2014; Min and Kim, 2012). It is clear from the recent review article by Min and Kim (2012) that very few attempts have been made to understand the GSCM nature in the developing countries context.

In addition to the above, service sector is becoming the lifeline for the social and economic growth of any country. It is well known that the contribution of the service sector to nation's progress is substantial. Services contribute twice the economic output compared with manufacturing (Rosenblum et al, 2000). Until today, only few studies have attempted to evaluate the performance of member firms of service supply chains. In particular, the environmental performance of member firms of service supply chains in a specific industry with respect to developing country context remains an unexplored area.

In addition to identification of suitable criteria for environmental performance evaluation through literature review and case studies, this paper proposes a grey based hybrid framework for evaluating the environmental performance of service supply chain members. The evaluation criteria are vague with most of them capturing intangible aspects. Since human judgments including preferences are often vague and cannot be expressed by exact numerical values, the application of the grey system theory for performance evaluation is an appropriate option. The grey approach has the ability to capture, process and integrate uncertainty in the decision making process. Since grey approach uses original data, the results are more relevant to practice (Golmohammadi and Mellat, 2012). Furthermore we found ELECTRE (ELimination and Choice Expressing the Reality) and VIKOR (the Serbian name: VlseKriterijumska Optimizacija I Kompromisno Resenje) approaches have most desirable properties such as insensitive to variation, capable to capture holistic aspects, suitability to accommodate different levels of measurements, simple to use and easy to implement which make these two approaches very much suitable for the task of evaluation. The framework proposed comprises of two hybrid approaches, the first developed by the integration of grey system theory and ELECTRE and the second developed by the integration of grey system theory and VIKOR. The framework proposed was applied to a case study available in the literature and the feasibility and practicability of the framework is validated. Two case studies were carried out to understand the evaluation criteria and effectiveness of the proposed framework with the member firms of service supply chains in a developing country context.

The remaining paper is organized as follows: Review of the supply chain environmental performance evaluation criteria is presented in section 2. In Section 3, the fundamentals of the grey system theory, the ELECTRE and the VIKOR approaches are discussed and the detailed procedural steps of the proposed framework for environmental performance evaluation are explained. In Section 4, two case studies on service supply chains were explained. Section 5 discusses the environmental performance evaluation with respect to the industry context. Section 6 validates the proposed framework with a published method and finally Section 7 summaries major findings and highlights the future research directions.

2. Environmental performance evaluation criteria for supply chains

Identification of appropriate criteria based on which the environmental performance evaluation of supply chains can be carried out is an important step in the whole exercise. Many authors have come up with a variety of environmental evaluation criteria for carrying out environmental performance evaluation of supply chains. The dynamic change of environmental criteria adds additional complexities for both practitioners and researchers. Environmental performance evaluation criteria suggested by various authors have been summarized based on the literature in Table 1. The most widely considered criterion is environmental management system. This major criterion is followed by green image, environmental performance, environmental competencies, design for environment, green competencies, corporate and social responsibilities, environmental efficiency, environmental authentication, environmental improvement cost, green logistic dimension, green organization activities, environmental certification, suppliers' green image, use of environmentally friendly material, use of environmentally friendly technology, waste management, reuse, recycle, green process innovation, green product, green purchasing, green project partnership and green design.

" Insert Table – 1 about here "

For the purpose of evaluating the environmental performance of supply chain members both qualitative and quantitative factors must be considered (Buyukozkan and Cifri, 2012a). Various factors like the sector of activity, range of products and services, size of the organization, quantum of value addition carried out and outsourcing philosophy of the organization can influence the list of evaluation criteria. Hence, appropriate evaluation criteria need to be identified for every environmental performance evaluation exercise. While carrying out an environmental performance evaluation exercise of service supply chains, the list of evaluation criteria employed should reflect specific aspects of the services in general and the services subsector in which the firms are operating in particular.

3. The proposed framework for environmental performance evaluation

3.1 Grey system theory

Grey system theory (Deng, 1988, 1989 and 2002), is one of the effective methods that are used to solve uncertainty problems under discrete data and incomplete information. The major advantage is that it can generate satisfactory outcomes using a relatively small amount of data or with great variability in factors. In grey system theory, according to the degree of information it accepts partial known information and partial unknown information.

Grey system theory considers the condition of fuzziness and flexibility in dealing with inconsistent information in group decision making situations. Grey system theory has been successfully applied in solving a variety of problems, such as hiring decision (Olson and Wu, 2006), restoration planning for power distribution systems (Chen, 2005), modeling of quality function deployment (Wu, 2002), detection of silicon wafer slicing defects (Lin et al., 2006), supplier selection (Yang, 2006), sustainability evaluation of suppliers (Bai and Sarkis, 2010 a, b; Baskaran et al., 2012), financial performance evaluation (Kung and Wen, 2007), demand forecasting (Wang, 2004) and evaluation of service quality (Kuo and Liang, 2011).

3.2 ELECTRE approach

The ELECTRE method is a family of multi criteria decision making methods developed by Roy (1973) to rank a set of alternatives. ELECTRE method is composed of a pair wise comparison of alternatives based on evaluated information provided by the decision maker. This method is concerned with concordance, discordance and outranking relationships. The algorithm uses concordance and discordance indices to analyze outranking relations among different alternatives and to choose the best alternative. The procedure of ELECTRE sequentially reduces the number of alternatives the decision maker is faced within a set of non-dominated alternatives. The ELECTRE method is quick, operates with simple logic and has the strength of being able to detect the presence of incomparability. It uses a systematic computational procedure an advantage of which is the absence of strong axiomatic assumptions. Other advantages of ELECTRE include the ability to take purely ordinal scales into account without the necessity of converting the original scales into abstract ones with an arbitrary imposed range (thus maintaining the original concrete verbal meaning), and the ability to take into consideration the decision makers' indifference and preference thresholds when modeling the imperfect knowledge of data.

The ELECTRE method has been applied in many real world applications like education system (Giannoulas and Ishizaka, 2010), plant location selection (Ozcan et al., 2011), facility layout planning (Aiello et al., 2006), supplier selection (Montazer, 2009; Sevkli, 2010; Liu and Zhang, 2011), optimization of energy systems (Papadopoulos and Karagiannidis, 2008), material suitability (Shanian and Savadogo, 2006), contract selection (De Almeida, 2007) and risk sorting of pipelines (Britto et al., 2010). The proposed framework links ELECTRE approach with grey environment to provide a systematic process to arrive at a ranking list based on the environmental performance of member firms of supply chains.

3.3 VIKOR Approach

VIKOR, the Serbian name: VlseKriterijumska Optimizacija I Kompromisno Resenje, means multi criteria optimization and compromise solution. Opricovic and Tzeng (2002, 2004) developed the VIKOR method for multi criteria optimization of complex systems. VIKOR method focuses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting criteria. Here, the compromise solution is a feasible solution which is the closest to the ideal, and a compromise means an agreement established by mutual concessions. The multi criteria measure for compromise ranking is developed from the *Lp*– metric that is used as an aggregating function in compromise programming.

The VIKOR method has been applied for many applications like selection of partners (Chen and Wang, 2009), service quality of airlines (Kuo and Liang, 2011; Liou et al., 2011), improving information security risk (Ou Yang et al., 2009), material selection (Jahan et al., 2011), renewable energy planning (San Cristobal, 2011) and water resources planning (Opricovic, 2011). The VIKOR approach is applied in the grey environment to provide a rational and systematic process to arrive at a ranking list based on the environmental performance of member firms of supply chains.

The hybrid MCDM framework proposed in this paper comprises of grey ELECTRE and grey VIKOR approaches which are very relevant to evaluate the environmental performance of service supply chain members. The algorithm of the framework proposed is described in Appendix - B.

4. Case studies

The framework proposed in this paper comprising of grey based ELECTRE and grey based VIKOR approaches can be employed for evaluating environmental performance of individual member firms of service supply chains. The different member firms of the supply chains are selected. A group of respondents having good expertise and experience in the areas of supply chain management and environmental protection and sufficient exposure to the sector in which the organization is operating, are identified and they are made members of the committee of the decision makers. This committee identifies the list of evaluation criteria based on which the environmental performance of different member firms of supply chains is to be evaluated.

The decision makers use the linguistic weighting methodology to assess the importance of the various criteria arrived at. The decision makers then evaluate the different supply chain member firms under analysis based on the criteria arrived at and award linguistic ratings. These linguistic ratings are converted into the corresponding grey numbers. The first approach of the proposed framework i.e. the grey based ELECTRE approach is applied to the evaluation data which is in the form of grey numbers. The outcome of the grey based ELECTRE procedure is a ranking list of the different member firms subjected to the analysis. Similarly the second approach of the proposed framework i.e. the grey based VIKOR approach is also applied to the evaluation data which is in the form of grey numbers. Similar to the grey based ELECTRE procedure, the grey VIKOR procedure also produces a ranking list of the different member firms subjected to the analysis. In addition, the grey based VIKOR procedure also recommends a Compromise Solution in case the best ranked firm does not enjoy acceptable advantage.

An organization can thus carry out an evaluation of environmental performance of different member firms of supply chains employed by it and get a ranking list of the firms using the proposed framework. The framework can also be made use of, for analyzing the environmental performance of new members of supply chains before they are incorporated as part of the supply chains.

Two detailed case studies were carried out, one in the health care sector and the other in the catering sector, where experts having good expertise and experience in the respective sectors are made members of the committee of decision makers, so that the performance analysis exercise is carried out in a systematic and efficient manner by utilizing the framework proposed in this paper.

4.1 Medical support service providers to hospitals

In the healthcare sector changes take place at a very rapid rate. Continual upgradation in the level of sophistication and the type of technology employed in the equipments, used for diagnosis and treatment is a regular phenomenon in this sector. The equipments generate solid and liquid chemicals as waste whereas some equipments are also capable of emitting harmful radiation. The pharmaceutical industry is regularly coming out with new drugs to replace the existing ones. Though the absolute quantity of pollutants generated by the healthcare sector is small, the potential for harmful effects on the human population and other flora and fauna is significant, if recycling, disposal and mitigation efforts are not proper.

In a developing country like India, where the per capita income is raising gradually and size of the population is also expected to maintain its pace of growth in the coming years, there is significant potential for growth in the healthcare sector. There is a pressing need that attempts are made to ensure that the expansion in the sector takes place without causing much environmental degradation. Mathur et al. (2011) reported that though legal provisions exist in India [Biomedical Waste (management and handling) Rules, 1998], to mitigate the impact of hazardous and infectious hospital waste on the community, these provisions are yet to be fully implemented.

It is essential that hospitals and medical practitioners monitor the environmental performance of medical support service providing firms to whom they are outsourcing. In this study, four Medical Support Service Providing firms (MSSPs) functioning in a city in South India were subjected to environmental performance analysis by implementing the proposed framework. These four MSSPs are providing medical support services to the hospitals in the city. The committee of decision makers formed for carrying out environmental performance evaluation of these MSSPs comprised of four experts, of whom three are medical practitioners in hospitals and the other one is an administrative officer in a hospital. The decision makers have 15, 18, 22 and 30 years of experience in the healthcare sector and are well exposed to working of MSSPs.

The committee of decision makers finalized eight criteria based on which the environmental performance of the four MSSPs were to be evaluated. For arriving at the list of evaluation criteria, the committee of decision makers considered all relevant aspects of the health care sector and also considered the various environmental performance evaluation criteria available in the literature. The criteria finalized were: Stakeholders' involvement and commitment (C_1), Adoption of green technologies and practices (C_2), Preference for environment friendly materials (C_3), Green collaboration (C_4), Regulatory conformance (C_5), Staff training and involvement (C_6), Recycling, reuse and disposal (C_7) and Green image (C_8).

The definitions of linguistic variables for importance of each criterion and the definitions of linguistic variables for the ratings of firms are given in Table 2. The decision makers analysed the importance of various criteria and awarded linguistic ratings for each criteria which are presented in Table 3. They assessed the four MSSPs based on the eight criteria and awarded linguistic values for each MSSP, which are available in Table 4. The grey number equivalents of the linguistic valuations are calculated using Equations (2) and (3). The normalized grey decision matrix and the weighted normalized grey decision matrix are calculated using Equations (7) and (9) respectively. The distances between alternatives for each criterion are calculated and are presented in Table A1. The concordance and discordance matrices are formulated using Equations (10) and (11) respectively and are shown in Table A2. The Boolean matrices E and F are constructed using Equations (12) and (14) respectively and are shown in Table A3. The global matrix G is constructed by peer to peer multiplication of the elements of the matrices E and F using Equation (16) and is presented in Table 5. The grey best value and the grey worst value for the eight criteria are found out using Equations (17) and (18). Using Equations (19) - (25), $\otimes S_i$, $\otimes R_i$, $\otimes S^*$, $\otimes S^-$, $\otimes R^*$, $\otimes R^-$and $\otimes Q_i$ values are calculated and are shown in Table 6. From the grey values of $\otimes S_i$ and $\otimes Q_i$, the equivalent crisp values are found out and are shown in Table 6. The ranking list of the four MSSPs subjected to the analysis is obtained as $MSSP_2 > MSSP_1 > MSSP_4 > MSSP_3$.

" *Insert Tables – 2,3,4,5 & 6 about here* "

4.2 Catering service providers to educational institutions

Catering Service Providers are another group of firms belonging to the category of service supply chain members. Since there is a lot of scope for improvement, the catering sector is capable of contributing a lot to the cause of environment protection. On the other hand, environmental degradation by the catering service providers can create a dent in the overall green image of the organizations that are outsourcing to the catering service providers. Hence, it is essential that organizations continuously analyse and monitor the environmental performance of the catering service providers, to whom the catering function is outsourced.

In this case study, the comparative environmental performance of four catering service providers operating in a city in South India with a population of 1.7 million was analysed. Most of the universities, educational institutions and non-formal educational and training institutions in this city, numbering around 30, are utilizing the services of these four catering service providers. Though the level of awareness on various aspects of environmental protection is high among students and staff of higher educational institutions as compared to the general population, the level of involvement and commitment to these aspects is not up to the desired levels, and hence there is a pressing need to have an institutionalized mechanism in place in the educational institutions to analyse and monitor the environmental performance of the supply chain members like the catering service providers. The committee of decision makers constituted for the purpose comprised of four senior and middle level faculty members associated with educational institutions in the city. The range of experience of the decision makers is 18 to 35 years. They have maintained consistent exposure to the catering activity in their respective educational institutions. The decision makers finalized seven criteria as the relevant ones for assessing the environmental performance of the CSPs. For arriving at the list of evaluation criteria, the committee of decision makers considered all relevant aspects of the catering sector and also considered the various environmental performance evaluation criteria available in the literature. The criteria were: Commitment of management (C_1), Adoption of green technologies and practices (C_2), Usage of green materials (C_3), Green collaboration initiatives (C_4), Regulatory conformance (C_5), Training and motivation of employees (C_6), and Recycling, reuse and disposal (C_7).

The four decision makers awarded linguistic valuations for the importance of seven criteria as shown in Table 7. They evaluated the four CSPs based on the seven criteria and awarded linguistic valuations as shown in Table 8. The grey number equivalents of the linguistic valuations are calculated using Equations (2) and (3). The normalized grey decision matrix and the weighted normalized grey decision matrix are calculated using Equations (7) and (9) respectively. The distances between alternatives for each criterion are calculated and are available in Table A4. The concordance and discordance matrices are formulated using Equations (10) and (11) respectively and are shown in Table A5. The Boolean matrices E and F are constructed using Equations (12) and (14) respectively and are shown in Table A6. The global matrix G is constructed by peer to peer multiplication of the elements of the matrices E and F using Equation (16) and is presented in Table 9. The grey best value and the grey worst value for the seven criteria are found out using Equations (17) and (18). Using Equations (19) - (25), $\otimes S_i$, $\otimes R_i$, $\otimes S^*$, $\otimes S^-$,$\otimes R^*$, $\otimes R^-$ and $\otimes Q_i$ values are calculated and are shown in Table 10. From the grey values of $\otimes S_i$ and $\otimes Q_i$, the equivalent crisp values are found out and are shown in Table 10. The ranking list of the four CSPs subjected to the analysis is obtained as $CSP_3 > CSP_2 > CSP_4 > CSP_1$.

" *Insert Tables – 7, 8, 9 & 10 about here* "

5. Discussion

Organizations today must respond to an increasing rate of change; product and technology life cycles are getting shorter, competitive pressures force rapid changes in the design of products and services, and consumer demand requires greater differentiation of products and services. They have to aim to achieve these customer expectations without causing any degradation to the environment. Environmental performance is a concern for all organizations today for reasons of regulatory and contractual compliance, public perception and competitive advantage. The number of environmentally conscious customers is growing and has passed a threshold size to justify introducing green offerings in certain industry sectors. Improved environmental performance can result in increasing the green image and thus, in higher sales and profits in the long term.

Only when all supply chain participants have adopted green and sustainable practices, the entire chain can easily be greened and collaboration among them becomes easier and more effective. Hence, it is absolutely essential that every organization constantly analyses and monitors the green performance of the different supply chains, the organization is making use of. Many critical drawbacks pervert the existing environmental performance evaluation methods from making a significant contribution to the greening efforts in supply chain management. The major drawbacks with the existing methods are: incapable to capture holistic aspects, lack of suitability to the different levels of measurement, complexity in methods, requirement of intricate details, inability to capture vagueness in human judgment etc. In this paper, we have proposed a pragmatic framework by integrating the grey system theory, the ELECTRE and the VIKOR for evaluating the environmental performance of member firms of service supply chains.

Since services possess intangibility, inseparability and heterogeneity, evaluating service supply chain performance is a complex task. Since the evaluation results from evaluator's view of linguistic variables, the analysis must be conducted in an uncertain environment. In order to overcome the issue, grey system theory needs to be incorporated into the performance analysis exercise. Grey system theory provides the suitable approach for analysis and modeling of systems with limited and incomplete information, and which may exhibit random uncertainty. The ELECTRE method is quick, operates with simple logic and has the strength of being able to detect the presence of incomparability. The major advantage of the VIKOR approach is that it also recommends a compromise solution in case the best ranked alternative does not enjoy acceptable advantage.

5.1 Medical support service providers to hospitals

Four medical support service providing firms (MSSPs) which are member firms of the healthcare supply chain belonging to the services sector, were subjected to the environmental performance evaluation exercise by implementing the framework proposed in this paper and the ranking list was obtained as $MSSP_2 > MSSP_1 > MSSP_4 > MSSP_3$. The decision makers awarded the highest importance to criteria C_4 (Green collaboration) which highlights the necessity to keep abreast of the environmental degradation potential and the related remedial strategies of the new technologies, equipment, drugs etc. emerging in this rapidly advancing and changing sector. Understandably, the criteria C_1 (Stakeholder's involvement and commitment) also received a very good rating from the decision makers.

$MSSP_2$ was awarded impressive linguistic values by all the decision makers in all evaluation criteria, except in the case of criteria C_3 (Preference for environment friendly materials) and hence emerged as the best performing firm. $MSSP_1$ scored modest rankings in criteria C_2 (Adoption of green technologies and practices) and in criteria C_8 (Green image) and hence could emerge only as the second ranked firm. $MSSP_4$ fared very poorly in the case of criteria C_3 (Preference for environment friendly materials) and criteria C_5 (Regulatory conformance) and hence got relegated to the third position. $MSSP_3$ got very poor rankings in six out of the eight criteria and is the worst performing firm.

5.2 Catering service providers to educational institutions

Four catering service providing firms (CSPs) providing catering services to the educational institutions, were subjected to the environmental performance evaluation exercise by implementing the proposed framework and the ranking list was obtained as $CSP_3 > CSP_2 > CSP_4 > CSP_1$.The decision makers awarded very good ratings to the following four criteria; Commitment of management (C_1), Usage of green materials (C_3), Regulatory conformance (C_5) and Recycling, reuse and disposal (C_7). CSP_3 was awarded impressive ratings for all criteria by all decision makers, except criteria C_2 (Adoption of green technologies and practices) and hence emerged as the best performing firm. CSP_2 received very good ratings for criteria C_4 (Green collaboration initiatives) and average ratings for all other criteria and emerged as the second best performing firm. CSP_4 scored moderate rankings in most of the criteria and hence got relegated to the third position. CSP_1 got very poor rankings in six out of the eight criteria and is the worst performing firm.

The framework proposed here, once incorporated and institutionalized into the organizations can be an effective tool for practicing managers of organizations to evaluate and monitor the environmental performance of service supply chain partners employed by the organizations. The framework is simple to learn and implement. The procedural steps are less time consuming both with or without the use of computers. The framework is free from accusations of bias and it is very much suitable for generalization and standardization. It can be applied for undertaking a systematic comparative analysis of environmental performance of members of service supply chains. It can also be applied for the process of incorporation of new members into the supply chains.

6. Validation of the proposed framework

The framework proposed in this paper was validated with a published data set. Awasthi et al. (2010) carried out an analysis at City Logistics Projects (SUCCESS) in La Rochelle, France for analyzing the environmental performance of supply chain members. They employed the following 12 criteria for the analysis: Use of environment friendly technology (C_1), Use of environment friendly materials (C_2), Green market share (C_3), Partnership with green organizations (C_4), Management commitment (C_5), Adherence to environmental policies (C_6), Green R & D projects (C_7), Staff training (C_8), Lean process planning (C_9), Design for environment (C_{10}), Environmental certification (C_{11}) and Pollution control initiatives (C_{12}).

The weights for importance of criteria suggested by the three decision makers and the ratings of the individual supply chain member firms are adopted from the paper by Awasthi et al. (2010) and are available in Tables 11 and 12 respectively. The linguistic valuations available in Tables 11 and 12 are converted into corresponding grey numbers for carrying out the calculations using Equations (2) and (3). The normalized grey decision matrix is constructed using Equation (7) and the weighted normalized grey decision matrix is formed using Equation (9). The distances between the alternatives for each criterion are calculated. The concordance and discordance matrices are formulated using Equations (10) and (11) respectively and are shown in Table A7. The Boolean matrices E and F are constructed using Equations (12) and (14) respectively and are shown in Table A8. The global matrix G is constructed by peer to peer multiplication of the elements of the matrices E and F using Equations (16) and is presented in Table 13. Thus the grey ELECTRE approach recommends the ranking order $A_1 > A_2 > A_3 > A_4$. A_1 emerges as the best ranked firm followed by A_2 and A_3.

The grey VIKOR methodology is applied to the linguistic valuations available in Tables 11 and 12. The grey best value and grey worst value for the twelve criteria used are calculated using Equations (17) and (18) respectively. Using Equations (19) - (25), $\otimes S_i$, $\otimes R_i$, $\otimes S^*$, $\otimes S^-$,$\otimes R^*$, $\otimes R^-$ and $\otimes Q_i$ values are calculated and are shown in Table 14. From the grey values of $\otimes S_i$and $\otimes Q_i$, the equivalent crisp values are found out and are shown in Table 14. Based on the Q_i values, it can be concluded that A_1 emerges as the best ranked firm. Since m = 4, DQ value is 0.25. So, the best ranked firm does not enjoy acceptable advantage. Hence, a set of compromise solutions is proposed. It consists of three firms, A_1 followed by A_3 and A_2.

" Insert Table – 11, 12, 13 & 14 about here "

7. Conclusion

Environmental management has become a vital issue for organisations as the emphasis on the environmental protection by organizational stakeholders, including stockholders, governments, customers, employees, competitors and communities keeps increasing. Programs such as design for the environment, life cycle analysis, total quality environmental management, green supply chain management and ISO 14000 standards have become widely practiced environmentally conscious practices. Both proactive and reactive methods have been implemented to protect the environment. With increasing government regulation and stronger public awareness in environmental protection, firms today simply cannot ignore environmental issues if they want to survive in the global market. In addition to complying with the environmental regulations for selling products and services in certain countries, firms need to implement strategies to voluntarily reduce the environmental impacts of their products and services. The integration of environment, economic and social performances to achieve sustainable development is a major business challenge for the new century.

With the growing awareness of environmental issues globally, governments and industry have recognized that they have vital roles in supporting and assuring sustainable development. For governments, laws and regulations have been issued to reduce and control greenhouse emissions, energy consumption, and environmental pollutions, etc. For industry, corporations are under tremendous pressure to comply with corporate social responsibility (CSR) requirements and to integrate environmental and social concerns in all spheres of activities. In consideration of the environmental concerns, companies worldwide have begun to adopt green supply chain management practices.

As Garvin (1993) said ‘‘If you cannot measure it, you cannot manage it’’, performance evaluation is an important part of the strategic management system of organizations as it affects the dynamics of the entire system. Performance evaluation in organizations serves the purposes of monitoring performance, identifying the areas that need attention, enhancing motivation, improving communications and strengthening accountability. GSCM performance evaluation that merely considers the initial inputs and the final outputs is in general insufficient since it ignores the relations among the divisions.

In this paper we developed a hybrid analytic framework for evaluating the environmental performance of member firms of service supply chains. The framework is free from accusations of bias and it is very much suitable for generalization and standardization. There is no restriction on the number of criteria or subcriteria. The framework developed was applied to a case analysis available in the literature and the feasibility and practicability of the framework was demonstrated. In the first case study carried out in the healthcare sector, appropriate metrics for evaluating the environmental performance of medical support service providers were identified by the committee of experts constituted for the purpose. Environmental performance of four medical support service providers were evaluated by employing the proposed framework and the ranking list based on their environmental performance was obtained.

In the second case study, appropriate metrics for evaluating the environmental performance of catering service providing firms were identified by the committee of experts constituted for the purpose. Environmental performance of four catering service providers providing catering service to educational institutions in a city in south India were evaluated by employing the proposed framework and the ranking list based on their environmental performance was obtained. Organizations operating in the services sector can thus carry out the analysis of environmental performance of different member firms of supply chains employed by them and get a ranking list of the firms using the proposed framework. The framework can also be made use of, for analyzing the environmental performance of new members of supply chains before they are incorporated as part of the supply chains.

As with any methodology, the proposed framework has a few limitations. Practicing managers need to be exposed and trained to apply the mathematical techniques involved. A comparative evaluation of the environmental performance of the different supply chain members can be carried out. However the absolute scores of the environmental performance of the member firms cannot be obtained. The environmental performance evaluation exercise by employing the proposed framework will be able to bring about the real picture in the supply chains only if experienced and competent people are appointed to the committee of decision makers. Lack of consensus opinion while gathering the criteria for evaluation can delay the speedy implementation of the methodologies proposed. There is a need that more academicians and practicing managers devote their attention towards developing appropriate metrics and methodologies for analyzing environmental performance of supply chains belonging to different sectors of services.

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Table 1 Evaluation criteria for environmental performance

Criteria	Authors
Adherence to environmental policies	Awasthi et al. (2010)
Air pollution treatment cost	Yeh and Chuang (2011)
Alternative green supply chain systems, projects, practices, etc.	Buyukozkan and Cifci (2011, 2012b)
Carbon footprint	Kumar and Jain (2010)
Cleaner production	Chen et al. (2010)
Compliance to Government regulations.	Handfield et al. (2002)
Current environmental efficiency	Noci (1997); Grisi et al. (2010)
Design for environment	Humphreys et al. (2003a, b), Humphreys et al. (2006), Awasthi et al. (2010)
Ecodesign	Hong-jun and Bin (2010)
Energy conservation	Lu et al. (2007), Shen et al. (2013)
Environment management system	Noci (1997), Zhang et al., (2003), Humphreys et al.,(2003a, b), Humphreys et al. (2006), Chiou et al. (2008), Li and Zhao (2009), Yan (2009),Lee et al. (2009), Tuzkaya et al. (2009), Chen et al. (2010), Grisi et al. (2010), Kuo et al. (2010), Shang et al. (2010),Thongchattu and Siripokapiram (2010), Shen et al. (2013)
Environment protection	Yang and Wu (2008)
Environmental authentication	Awasthi et al. (2010), Hong-jun and Bin (2010)
Environmental commitment	Large and Thomsen (2011)
Environmental competences	Humphreys et al., (2003a, b), Humphreys et al. (2006), Grisi et al. (2010)
Environmental performance	Chiou et al. (2008), Chiou et al. (2011), Feyzioglu and Buyukozkan (2010), Large and Thomsen (2011)
Environmental programs at the supplier's facilities	Handfield et al. (2002)
Environmental improvement costs	Humphreys et al., (2003a, b), Humphreys et al. (2006), Tuzkaya et al. (2009), Kuo et al. (2010)
Green product performance	Wen and Chi (2010)

Green collaboration with suppliers	Large and Thomsen (2011)
Green certification	Awasthi et al. (2010), Tseng (2011)
Green competencies	Noci (1997), Humphreys et al. (2003a,b), Chiou et al. (2008), Lee et al. (2009),
Green design	Chen et al. (2010)
Green image	Noci (1997),Humphreys et al., (2003a, b), Humphreys et al. (2006),Lee et al. (2009), Tuzkaya et al. (2009), Grisi et al. (2010),Shen et al. (2013),
Green knowledge transfer	Bai and Sarkis (2010a)
Green logistics dimension	Buyukozkan and Cifci (2011, 2012b)
Green management system	Wen and Chi (2010)
Green managerial innovation	Chiou et al. (2011)
Green market share	Awasthi et al. (2010)
Green organizational activities dimension	Buyukozkan and Cifci (2011, 2012b)
Green process	Hsu and Hu (2009), Tuzkaya et al. (2009), Tseng (2011)
Green process innovation	Chiou et al. (2011)
Green product	Noci (1997), Humphreys et al. (2003a,b), Lee et al. (2009), Tuzkaya et al. (2009), Kuo et al. (2010), Shang et al.(2010), Tseng (2011), Shen et al. (2013)
Green product innovation	Chiou et al. (2011)
Green projects partnership	Vachon and Klassen (2006)
Green purchasing	Lu et al. (2007), Hsu and Hu (2009), Chen et al. (2010), Shang et al. (2010), Tseng (2011), Shen et al. (2013)
Green R & D Projects	Awasthi et al. (2010)
Green supplier assessment	Large and Thomsen (2011)
Greening the supplier	Chiou et al. (2011)
Management support	Humphreys et al. (2003a,b), Hsu and Hu (2009), Awasthi et al. (2010), Kuo et al. (2010), Tseng (2011), Shen et al. (2013)
Internal green production plan	Chen et al. (2010)
Partnership with green organization	Awasthi et al. (2010)
Pollution control	Lee et al. (2009), Tuzkaya et al. (2009), Tseng (2011), Shen et al. (2013)
Pollution control initiatives	Awasthi et al. (2010)
Purchasing's environmental capabilities	Large and Thomsen (2011)
R&D green products	Chen et al. (2010)
Regulatory conformance	Tuzkaya et al. (2009)
Recycle	Bala et. al (2008)
Reuse	Bala et. al (2008)
Social responsibility & environmental competencies	Buyukozkan and Cifci (2011, 2012b)
Supplier's green image	Noci (1997), Wen and Chi (2010)

Staff environmental training	Awasthi et al. (2010), Shen et al. (2013)
Use of environmental friendly materials	Awasthi et al. (2010)
Use of environment friendly technology	Lu et al. (2007), Hsu and Hu (2009), Lee et al. (2009), Awasthi et al. (2010), Tseng (2011), Shen et al. (2013)
Waste management	Handfield et al. (2002)

Table 2

Definitions of linguistic variables for importance of criteria and for the ratings of firms

For the importance of criteria		For the ratings of firms	
Linguistic Variables	**Grey numbers**	**Linguistic Variables**	**Grey numbers**
Very Low (VL)	(0.0, 0.3)	Very Poor (VP)	(0, 3)
Low (L)	(0.1, 0.5)	Poor (P)	(1, 5)
Medium (M)	(0.3, 0.7)	Fair (F)	(3, 7)
High(H)	(0.5, 0.9)	Good(G)	(5, 9)
Very High (VH)	(0.7, 1.0)	Very Good (VG)	(7, 10)

Table 3

MSSPs: Linguistic assessments for the 8 criteria

Criteria	**Decision Makers**			
	D_1	***D_2***	***D_3***	***D_4***
C_1	M	VH	H	VH
C_2	L	H	M	H
C_3	M	L	M	H
C_4	H	VH	VH	H
C_5	L	VL	VL	L
C_6	M	L	L	M
C_7	H	M	M	VH
C_8	L	M	L	L

Table 4

MSSPs: Linguistic assessments for the four alternatives

Criteria	**Alternatives**															
	$MSSP_1$				**$MSSP_2$**				**$MSSP_3$**				**$MSSP_4$**			
	D_1	***D_2***	***D_3***	***D_3***	***D_1***	***D_2***	***D_3***	***D_4***	***D_1***	***D_2***	***D_3***	***D_4***	***D_1***	***D_2***	***D_3***	***D_4***
C_1	G	F	F	G	G	VG	G	VG	F	F	P	F	F	G	G	G

C_2	F	F	P	F	F	G	G	G	P	P	VP	F	G	F	F	P
C_3	G	F	P	F	F	P	P	F	P	F	P	P	P	VP	VP	F
C_4	G	F	F	G	VG	G	VG	G	F	P	F	P	G	G	VG	G
C_5	G	G	F	G	F	F	P	F	F	G	F	G	F	P	P	F
C_6	G	G	G	G	VG	VG	G	VG	F	G	F	G	G	G	VG	G
C_7	F	G	F	F	G	F	G	G	P	F	P	F	F	G	F	F
C_8	F	P	P	F	VG	G	G	VG	F	P	VP	P	G	G	F	G

Table 5

MSSPs:The global matrix G

m	$MSSP_1$	$MSSP_2$	$MSSP_3$	$MSSP_4$
$MSSP_1$	-	0	1	1
$MSSP_2$	1	-	1	1
$MSSP_3$	0	0	-	0
$MSSP_4$	0	0	1	-

Table 6

MSSPs: Sum of distances, decision coefficients and ranks of the firms

m	Grey sum of distances		Crisp value	Extreme values	Grey decision coefficient		Crisp value	Rank
$MSSP_1$	1.256	2.39	1.825	$\otimes S^* = (0.19, 0.6)$	0.419	0.337	0.378	2
$MSSP_2$	0.19	0.6	0.395	$\otimes S^- = (2.452, 4.504)$	0.0	0.0	0.0	1
$MSSP_3$	2.451	4.5	3.478	$\otimes R^* = (0.15, 0.32)$	1.0	1.0	1.0	4
$MSSP_4$	1.13	2.323	1.726	$\otimes R^- = (0.6, 0.825)$	0.375	0.597	0.486	3

Table 7

CSPs: Linguistic assessments for the 7 criteria

Criteria	Decision Makers			
	D_1	D_2	D_3	D_4
C_1	VH	H	VH	H
C_2	M	L	M	L
C_3	H	VH	H	VH
C_4	H	M	VH	M
C_5	VH	H	VH	VH
C_6	M	VH	H	M
C_7	VH	M	VH	VH

Table 8

CSPs: Linguistic assessments for the four alternatives

Criteria	Alternatives															
	CSP_1				CSP_2				CSP_3				CSP_4			
	D_1	D_2	D_3	D_3	D_1	D_2	D_3	D_4	D_1	D_2	D_3	D_4	D_1	D_2	D_3	D_4
C_1	F	P	P	VP	G	F	F	G	G	G	VG	VG	F	F	P	P
C_2	F	G	P	G	P	P	G	P	F	P	F	P	G	F	P	G
C_3	P	VP	F	VP	G	F	F	F	G	VG	G	G	P	P	F	P
C_4	P	P	P	P	VG	F	VG	G	F	VG	F	G	P	F	F	P
C_5	P	VP	F	P	G	F	F	G	G	F	G	G	F	P	F	P
C_6	F	F	P	F	G	F	F	F	F	G	G	F	F	P	F	F
C_7	P	F	VP	VP	G	G	F	G	G	VG	F	VG	P	F	P	P

Table 9

CSPs: The global matrix G

m	CSP_1	CSP_2	CSP_3	CSP_4
CSP_1	-	0	0	0
CSP_2	1	-	0	1
CSP_3	1	1	-	1
CSP_4	1	0	0	-

Table 10

CSPs: Sum of distances, decision coefficients and ranks of the firms

m	Grey sum of distances		Crisp value	Extreme values	Grey decision coefficient		Crisp value	Rank
CSP_1	3.35	5.45	4.4	$\otimes S^* = (0.3, 0.755)$	1.0	1.0	1.0	4
CSP_2	1.17	1.726	1.448	$\otimes S^- = (3.35, 5.45)$	0.476	0.108	0.292	2
CSP_3	0.3	0.755	0.527	$\otimes R^* = (0.2, 0.6)$	0.0	0.0	0.0	1

CSP_4	3.006	4.214	3.61	$\otimes R^{-} = (0.65, 0.975)$	0.933	0.668	0.801	3

Table 11

Logistics Project: Linguistic assessments for the 12 criteria

Source: Awasthi et al. (2010)

Criteria	**Decision Makers**		
	D_1	***D_2***	***D_3***
C_1	H	H	M
C_2	L	VH	L
C_3	M	VH	VH
C_4	VH	VH	VH
C_5	VL	VH	M
C_6	H	M	VH
C_7	H	M	M
C_8	L	VH	H
C_9	VL	M	VH
C_{10}	M	VH	VH
C_{11}	VL	L	L
C_{12}	VH	VL	VH

Table 12

Logistics Project: Linguistic assessments for the four alternatives

Source: Awasthi et al. (2010)

Criteria	**Alternatives**											
	A_1			**A_2**			**A_3**			**A_4**		
	D_1	***D_2***	***D_3***	***D_1***	***D_2***	***D_3***	***D_1***	***D_2***	***D_3***	***D_1***	***D_2***	***D_3***
C_1	P	F	P	VP	F	VG	VG	G	VG	VP	VG	VG
C_2	VG	VG	G	VG	F	P	P	VP	G	VG	P	F
C_3	F	G	VG	VP	P	P	P	P	G	VG	G	F
C_4	P	VG	VG	G	F	VP	G	F	VG	VP	VP	VP
C_5	F	G	VG	P	P	VG	VP	VP	VP	F	VP	P

C_6	P	VP	F	G	F	VP	VG	F	F	P	VP	F
C_7	VP	G	F	VG	VP	VG	G	VP	VG	VG	P	P
C_8	VP	VP	G	G	VG	VG	F	VG	VP	G	G	VP
C_9	F	VG	F	VP	P	VG	F	F	VP	P	VG	VG
C_{10}	G	G	VG	F	VP	F	F	G	VP	P	G	P
C_{11}	P	VG	VP	G	G	G	F	F	G	G	F	G
C_{12}	G	P	VG	G	G	F	F	P	VG	VG	VG	VG

Table 13

Logistics Project: The global matrix G

m	**A_1**	**A_2**	**A_3**	**A_4**
A_1	-	1	1	1
A_2	0	-	0	1
A_3	0	0	-	0
A_4	0	0	0	-

Table 14

Logistics Project: Sum of distances, decision coefficients and ranks of the firms

m	**Grey sum of distances**		**Crisp value**	**Extreme values**	**Grey decision coefficient**		**Crisp value**	**Rank**
A_1	2.248	4.415	3.331	$\otimes S^* = (2.248, 4.415)$	0.072	0.214	0.143	1
A_2	2.967	5.004	3.986	$\otimes S^- = (2.967, 5.004)$	0.715	0.786	0.75	3
A_3	2.712	4.883	3.798	$\otimes R^* = (0.467, 0.767)$	0.323	0.397	0.36	2
A_4	2.902	4.965	3.933	$\otimes R^- = (0.7, 1.0)$	0.955	0.967	0.961	4

Appendix – A: Grey Arithmetic

Let X be the universal set. A grey set G of X is defined by its two mappings .

$$G = \begin{cases} \overline{\mu}_G(x) : x \longrightarrow [0,1] \\ \underline{\mu}_G(x) : x \longrightarrow [0,1] \end{cases} \quad (1)$$

where $\overline{\mu}_G(x) \geq \underline{\mu}_G(x),\ x \in X,\ X = R$

A grey number is one of which the exact value is unknown, while the upper and/or the lower limits can be estimated. Generally, grey number is written as $\otimes x$, $\left(\otimes x = x\Big|_{\underline{\mu}}^{\overline{\mu}}\right)$.

If only the lower limit of x can be possibly estimated, x is defined as lower limit grey number and if only the upper limit of x can be estimated, x is defined as upper limit grey number. If the lower and upper limits of x can be estimated, x is defined as interval grey number.

The basic operation laws of grey numbers $\otimes x_1 = [\underline{x}_1, \overline{x}_1]$ and $\otimes x_2 = [\underline{x}_2, \overline{x}_2]$ are expressed as follows:

Addition: $\otimes x_1 + \otimes x_2 = [\underline{x}_1 + \underline{x}_2, \overline{x}_1 + \overline{x}_2]$

Subtraction: $\otimes x_1 - \otimes x_2 = [\underline{x}_1 - \underline{x}_2, \overline{x}_1 - \overline{x}_2]$

Multiplication: $\otimes x_1 \times \otimes x_2 = \begin{bmatrix} \min(\underline{x}_1\underline{x}_2, \underline{x}_1\overline{x}_2, \overline{x}_1\underline{x}_2, \overline{x}_1\overline{x}_2), \\ \max(\underline{x}_1\underline{x}_2, \underline{x}_1\overline{x}_2, \overline{x}_1\underline{x}_2, \overline{x}_1\overline{x}_2) \end{bmatrix}$

Division: $\otimes x_1 \div \otimes x_2 = [\underline{x}_1, \overline{x}_1] \times \left[\frac{1}{\underline{x}_2}, \frac{1}{\overline{x}_2}\right]$

The Modowski space distance of two grey numbers $\otimes x_1$ and $\otimes x_2$ is defined as

$$L(\otimes x_1, \otimes x_2) = \left[(\underline{x}_1 - \underline{x}_2)^p + (\overline{x}_1 - \overline{x}_2)^p\right]^{\frac{1}{p}}$$

Appendix –B:

Algorithm of the proposed framework for analysing environmental performance of member firms of service supply chains

The algorithm of the proposed framework formed by integrating ELECTRE, VIKOR and grey approaches is described in the following steps:

Step 1: Generate the list of all feasible alternatives. Form a committee of decision makers who are experts in the field commanding good expertise and experience. The committee of decision makers arrives at the list of evaluation criteria to be considered for determining the ranking of alternatives.

Step 2: Define linguistic variables and their corresponding grey numbers for the weight of criteria and the rating of alternatives respectively.

Step 3: Integrate decision makers' preferences and opinions. The decision is derived by aggregating the grey weights of criteria from *n* decision makers calculated as

$$\otimes w_j = \frac{1}{n}\left[\sum_{e=1}^{n} \otimes w_j^e\right], \quad j = 1,2,\dots,k \tag{2}$$

The rating of each alternative based on the preferences and opinions of *n* decision makers with respect to *j* criteria can be calculated by

$$\otimes x_{ij} = \frac{1}{n}\left[\sum_{e=1}^{n} \otimes x_j^e\right], \quad i = 1,2,\dots,m \tag{3}$$

Step 4: Calculate grey weighted average and construct the grey decision matrix as given below:

$$\otimes D = \begin{bmatrix} \otimes x_{11} & \otimes x_{12} & \cdots & \otimes x_{1k} \\ \otimes x_{21} & \otimes x_{22} & \cdots & \otimes x_{2k} \\ \vdots & \vdots & \otimes x_{ij} & \vdots \\ \otimes x_{m1} & \otimes x_{m2} & \cdots & \otimes x_{mk} \end{bmatrix} \tag{4}$$

$$i = 1,2,\dots,m; \; j = 1,2,\dots,k$$

$$\otimes W = \left[\otimes w_1, \otimes w_2, \dots, \otimes w_j, \dots, \otimes w_k\right], \; j = 1,2,\dots,k \tag{5}$$

Where $\otimes x_{ij}$ is the rating of alternative A_i with respect to criterion C_j and $\otimes w_j$ is the importance weight of the j th criterion.

*Step 5:*Normalise the grey decision matrix. The normalized grey decision matrix is constructed as follows:

$$\otimes R = [\otimes r_{ij}]_{m\times n} \tag{6}$$

$$\otimes r_{ij} = [r_{ij}^{l}, r_{ij}^{u}] = \left[\frac{x_{ij}^{l}}{C_j^*}, \frac{x_{ij}^{u}}{C_j^*}\right], \; i = 1,2,\ldots m, \quad j \in B \tag{7}$$

where $C_j^* = \max_i x_{ij}^u$, $j \in B$

Step 6: Compute the weighted normalized grey decision matrix. Assuming that the importance weights of the attributes are different, the weighted normalized grey decision matrix is obtained by multiplying the importance weights of the attributes and the values in the normalized grey decision matrix.

$$\otimes V = [\otimes v_{ij}]_{m\times n} \tag{8}$$

$$\otimes v_{ij} = [v_{ij}^{l}, v_{ij}^{u}] = \otimes w_j (\times) \otimes r_{ij} = [w_j^l r_{ij}^l, w_{ij}^u r_{ij}^u] \tag{9}$$

Step 7: Calculate the distance between any two alternatives. Paired comparison among the alternatives is carried out by utilizing the weighted normalized grey decision matrix and the distances between the various alternatives are calculated.

Step 8: Construct the concordance and discordance matrices. The concordance and discordance matrices are constructed based on the distances between the various alternatives as detailed below:

$$\otimes C = \begin{bmatrix} - & \otimes C_{1q} & \cdots & \otimes C_{1m} \\ \otimes C_{p1} & - & \cdots & \otimes C_{pm} \\ \vdots & \vdots & \otimes C_{pq} & \vdots \\ \otimes C_{m1} & \otimes C_{mq} & \cdots & - \end{bmatrix} \tag{10}$$

where $\otimes C_{pq} = [C_{pq}^{l}, C_{pq}^{u}] = [\sum_{j\epsilon J^C} \otimes w_j^l , \sum_{j\epsilon J^C} \otimes w_j^u]$

$$D = \begin{bmatrix} - & d_{1q} & \cdots & d_{1m} \\ d_{p1} & - & \cdots & d_{pm} \\ \vdots & \vdots & d_{pq} & \vdots \\ d_{m1} & d_{mq} & \cdots & - \end{bmatrix} \tag{11}$$

and the discordance level is defined as $\overline{D} = \sum_{p=1}^{m} \sum_{q=1}^{m} \frac{d_{pq}}{m(m-1)}$

Step 9: Construct the Boolean matrices E and F. The Boolean matrix E is determined based on the minimum concordance level, as follows:

$$E = \begin{bmatrix} - & e_{1q} & \cdots & e_{1m} \\ e_{p1} & - & \cdots & e_{pm} \\ \vdots & \vdots & e_{pq} & \vdots \\ e_{m1} & e_{mq} & \cdots & - \end{bmatrix} \tag{12}$$

$$\text{where } \begin{cases} \otimes c_{pq} \geq \otimes \overline{C} \implies e_{pq} = 1 \\ \otimes c_{pq} < \otimes \overline{C} \implies e_{pq} = 0 \end{cases} \tag{13}$$

Similarly, the Boolean matrix F is obtained based on the minimum discordance level as follows:

$$F = \begin{bmatrix} - & f_{1q} & \cdots & f_{1m} \\ f_{p1} & - & \cdots & f_{pm} \\ \vdots & \vdots & f_{pq} & \vdots \\ f_{m1} & f_{mq} & \cdots & - \end{bmatrix} \tag{14}$$

$$\text{where } \begin{cases} d_{pq} < \overline{D} \implies f_{pq} = 1 \\ d_{pq} \geq \overline{D} \implies f_{pq} = 0 \end{cases} \tag{15}$$

Step 10: Construct the general matrix. By peer to peer multiplication of the elements of the matrices E and F, the general matrix G is constructed as

$$G = E\,(\times)\,F \tag{16}$$

Step 11: Determine the grey best value(GBV) and the grey worst value(GWV) :

$$\otimes f_j^* = \max_i \otimes x_{ij} \tag{17}$$

$$\otimes f_j^- = \min_i \otimes x_{ij} \tag{18}$$

Step 12: Calculate the values $\frac{\otimes w_j\ (\otimes f_j^* - \otimes x_{ij})}{(\otimes f_j^* - \otimes f_j^-)}$, $\otimes S_i$, $\otimes R_i$

$$\otimes S_i = \sum_{j=1}^{k} \otimes w_j\left(\otimes f_j^* - \otimes x_{ij}\right)/\left(\otimes f_j^* - \otimes f_j^-\right) \tag{19}$$

$$\otimes R_i = \max_j\left[\otimes w_j\left(\otimes f_j^* - \otimes x_{ij}\right)/\left(\otimes f_j^* - \otimes f_j^-\right)\right] \tag{20}$$

where $\otimes S_i$ is A_i with respect to all criteria calculated by the sum of the distances from the GBV, and $\otimes R_i$ is A_i with respect to the j th criterion, calculated by maximum distance from GBV.

Step 13: Calculate the values $\otimes S^*$, $\otimes S^-$, $\otimes R^*$, $\otimes R^-$ and $\otimes Q_i$:

$$\otimes S^* = \min_i \otimes S_i \tag{21}$$

$$\otimes S^- = \max_i \otimes S_i \tag{22}$$

$$\otimes R^{*} = \min_{i} \otimes R_i \tag{23}$$

$$\otimes R^{-} = \max_{i} \otimes R_i \tag{24}$$

$$\otimes Q_i = v(\otimes S_i - \otimes S^{*})/(\otimes S^{-} - \otimes S^{*}) + (1-v)\,(\otimes R_i - \otimes R^{*})/(\otimes R^{-} - \otimes R^{*}) \tag{25}$$

Step 14: Arrive at the crisp equivalent of the grey number $\otimes Q_i$ and rank the alternatives, sorting by the value Q_i in ascending order. Consequently, the smaller the value of Q_i , the better the alternative.

Step 15: Determine a compromise solution. Assume that the two conditions given below are acceptable. Then by using the index Q_i , determine a compromise solution (a') as a single optimal solution.

[C1] Acceptable advantage:

$$Q(a'') - Q(a') \geq DQ \tag{26}$$

$$DQ = {}^{1}/_{m-1} \qquad (DQ = 0.25 \ \ if \ \ m \leq 4) \tag{27}$$

[C2] Acceptable stability in decision making:

Under this condition $Q(a')$ must be $S(a')$ or/and $R(a')$.

If [C1] is not accepted and $Q\left(a^{(m)}\right) - Q(a') < DQ$, then $a^{(m)}$ and a' are the same compromise solution. However, a' does not have a comparative advantage, so the compromise solutions $a', a'', \dots, a^{(m)}$ are the same. If the [C2] is not accepted, the stability in decision making is deficient, although a' has a comparative advantage. Hence, compromise solutions of a' and a'' are the same.

Appendix C

Table A1

MSSPs: The distance between the alternatives for each criteria

	C_1					*C_2*			
	X_1	**X_2**	**X_3**	**X_4**		**X_1**	**X_2**	**X_3**	**X_4**
X_1	-	(0.246,0)	(0,0.281)	(0.085,0)	**X_1**	-	(0.34,0)	(0,0.365)	(0.119,0)
X_2	-	-	(0,0.45)	(0,0.178)	**X_2**	-	-	(0,0.567)	(0,0.255)
X_3	-	-	-	(0.34,0)	**X_3**	-	-	-	(0.434,0)
X_4	-	-	-	-	**X_4**	-	-	-	-
	C_3					*C_4*			
	X_1	**X_2**	**X_3**	**X_4**		**X_1**	**X_2**	**X_3**	**X_4**
X_1	-	(0,0.238)	(0,0.357)	(0,0.512)	**X_1**	-	(0.246,0)	(0,0.375)	(0.204,0)
X_2	-	-	(0,0.167)	(0,0.375)	**X_2**	-	-	(0,0.518)	(0,0.055)
X_3	-	-	-	(0,0.257)	**X_3**	-	-	-	(0.492,0)
X_4	-	-	-	-	**X_4**	-	-	-	-
	C_5					*C_6*			
	X_1	**X_2**	**X_3**	**X_4**		**X_1**	**X_2**	**X_3**	**X_4**
X_1	-	(0,0.34)	(0,0.086)	(0,0.424)	**X_1**	-	(0.205,0)	(0,0.1)	(0.116,0)
X_2	-	-	(0.283,0)	(0,0.136)	**X_2**	-	-	(0,0.282)	(0,0.103)
X_3	-	-	-	(0,0.374)	**X_3**	-	-	-	(0.204,0)
X_4	-	-	-	-	**X_4**	-	-	-	-
	C_7					*C_8*			
	X_1	**X_2**	**X_3**	**X_4**		**X_1**	**X_2**	**X_3**	**X_4**
X_1	-	(0.17,0)	(0,0.314)	(0,0)	**X_1**	-	(0.517,0)	(0,0.272)	(0.425,0)
X_2	-	-	(0,0.425)	(0,0.17)	**X_2**	-	-	(0,0.633)	(0,0.178)
X_3	-	-	-	(0.314,0)	**X_3**	-	-	-	(0.567,0)
X_4	-	-	-	-	**X_4**	-	-	-	-

Table A2

MSSPs: The concordance matrix and the discordance matrix

m	Concordance matrix				Discordance matrix			
	$MSSP_1$	**$MSSP_2$**	**$MSSP_3$**	**$MSSP_4$**	**$MSSP_1$**	**$MSSP_2$**	**$MSSP_3$**	**$MSSP_4$**
$MSSP_1$	-	(0.35,1.1)	(2.65,5.375)	(0.8,1.925)	-	1.0	0	0.83
$MSSP_2$	(2.3,4.275)	-	(2.65,5.375)	(2.65,5.375)	0.658	-	0.447	0
$MSSP_3$	(0,0)	(0,0)	-	(0.35,1.1)	1.0	1.0	-	1.0
$MSSP_4$	(2.3,4.275)	(0,0)	(2.3,4.275)	-	1.0	1.0	0.868	-

Table A3

MSSPs: The Boolean matrices E and F

m	Matrix E				Matrix F			
	$MSSP_1$	**$MSSP_2$**	**$MSSP_3$**	**$MSSP_4$**	**$MSSP_1$**	**$MSSP_2$**	**$MSSP_3$**	**$MSSP_4$**
$MSSP_1$	-	0	1	1	-	0	1	1
$MSSP_2$	1	-	1	1	1	-	1	1
$MSSP_3$	0	0	-	0	0	0	-	0
$MSSP_4$	1	0	1	-	0	0	1	-

Table A4

CSPs: The distance between the alternatives for each criteria

	C_1					C_2			
	X_1	**X_2**	**X_3**	**X_4**		**X_1**	**X_2**	**X_3**	**X_4**
X_1	-	(0.594,0)	(0.685,0)	(0.354,0)	**X_1**	-	(0,0.314)	(0,0.314)	(0,0)
X_2	-	-	(0.246,0)	(0,0.375)	**X_2**	-	-	(0,0)	(0.314,0)
X_3	-	-	-	(0,0.518)	**X_3**	-	-	-	(0.314,0)
X_4	-	-	-	-	**X_4**	-	-	-	-
	C_3					C_4			
	X_1	**X_2**	**X_3**	**X_4**		**X_1**	**X_2**	**X_3**	**X_4**
X_1	-	(0.557,0)	(0.666,0)	(0.259,0)	**X_1**	-	(0.633,0)	(0.587,0)	(0.336,0)
X_2	-	-	(0.276,0)	(0,0.418)	**X_2**	-	-	(0,0.134)	(0,0.485)
X_3	-	-	-	(0,0.566)	**X_3**	-	-	-	(0,0.413)
X_4	-	-	-	-	**X_4**	-	-	-	-
	C_5					C_6			
	X_1	**X_2**	**X_3**	**X_4**		**X_1**	**X_2**	**X_3**	**X_4**
X_1	-	(0.531,0)	(0.566,0)	(0.27,0)	**X_1**	-	(0.211,0)	(0.283,0)	(0,0)
X_2	-	-	(0.084,0)	(0,0.375)	**X_2**	-	-	(0.095,0)	(0,0.211)

X_3	-	-	-	(0,0.424)	X_3	-	-	-	(0,0.283)
X_4	-	-	-	-	X_4	-	-	-	-
	C_7								
	X_1	X_2	X_3	X_4					
X_1	-	(0.625,0)	(0.659,0)	(0.26,0)					
X_2	-	-	(0.118,0)	(0,0.509)					
X_3	-	-	-	(0,0.557)					
X_4	-	-	-	-					

Table A5

CSPs: The concordance matrix and the discordance matrix

	Concordance matrix				Discordance matrix			
m	CSP_1	CSP_2	CSP_3	CSP_4	CSP_1	CSP_2	CSP_3	CSP_4
CSP_1	-	0.2,0.6	0.2,0.6	0.65,1.43	-	1.0	1.0	1.0
CSP_2	3.35,5.45	-	0.65,1.43	3.35,5.45	0.496	-	1.0	0.617
CSP_3	3.35,5.45	3.1,5.225	-	3.35,5.45	0.458	0.207	-	0.555
CSP_4	3.55,6.05	0.2,0.6	0.2,0.6	-	0	1.0	1.0	-

Table A6

CSPs: The Boolean matrices E and F

	Matrix E				Matrix F			
m	CSP_1	CSP_2	CSP_3	CSP_4	CSP_1	CSP_2	CSP_3	CSP_4
CSP_1	-	0	0	0	-	0	0	0
CSP_2	1	-	0	1	1	-	0	1
CSP_3	1	1	-	1	1	1	-	1
CSP_4	1	0	0	-	1	0	0	-

Table A7

Logistics Project: The concordance matrix and the discordance matrix

	Concordance matrix				Discordance matrix			
m	A_1	A_2	A_3	A_4	A_1	A_2	A_3	A_4
A_1	-	(2.8,4.8)	(2.567,4.567)	(2.967,5.0)	-	0.736	0.554	0.38
A_2	(2.267,4.467)	-	(2.3,4.767)	(3.433,5.367)	1.0	-	0.539	0.809
A_3	(2.5,4.7)	(2.767,4.5)	-	(2.567,4.367)	1.0	1.0	-	0.847

A_4	(2.633,4.833)	(2.667,4.733)	(2.5,4.9)	-	1.0	1.0	1.0	-

Table A8

Logistics Project: The Boolean matrices E and F

	Matrix E				Matrix F			
m	**A_1**	**A_2**	**A_3**	**A_4**	**A_1**	**A_2**	**A_3**	**A_4**
A_1	-	1	1	1	-	1	1	1
A_2	0	-	0	1	0	-	1	1
A_3	1	1	-	0	0	0	-	1
A_4	1	1	1	-	0	0	0	-

Appendix – D Model Calculations

A set of model calculations is presented below for the first case study where environmental performance analysis of medical support service providers was carried out:

The linguistic valuations awarded by the decision makers are converted into their equivalent grey numbers. For the criteria C_1, the linguistic valuations awarded by the four decision makers are { M, VH, H, VH }. The equivalent grey number is arrived at as $\left(\frac{(0.3+0.7+0.5+0.7)}{4}, \frac{(0.7+1.0+0.9+1.0)}{4}\right) = (0.55, 0.9)$.

For the MSSP$_1$, the linguistic valuation awarded by the four decision makers for the criteria C_1 are { G, F, F, G }. The equivalent grey number is arrived at as $\left(\frac{(5+3+3+5)}{4}, \frac{(9+7+7+9)}{4}\right) = (4, 8)$.

Using Eq (6) and (7), the normalized grey value is calculated as

$$\left(\frac{4}{9.75}, \frac{8}{9.75}\right) = (0.41, 0.821).$$

Using Eq (8) and (9), the weighted normalized grey value is calculated as

$$(0.55 * 0.41, 0.9 * 0.821) = (0.226, 0.739)$$

Using Eq (17) and (18), the grey best value and the grey worst value for the criteria C_1 are calculated as (6, 9.5) and (2.5, 6.5) respectively.

Using Eq (19), the value of grey sum of distances, $\otimes S_i$ is calculated for MSSP$_1$ as

$$\left(\frac{0.55(6-4)}{6-2.5}+\frac{0.35(4.5-2.5)}{4.5-1.25}+\frac{0.3(3-3)}{3-1}+\frac{0.6(6-4)}{6-2}+\frac{0.05(4.5-4.5)}{4.5-2}\right.$$

$$+\frac{0.2(6.5-5)}{6.5-4}+\frac{0.45(4.5-3.5)}{4.5-2}+\frac{0.15(6-2)}{6-1.25},\frac{0.9(9.5-8)}{9.5-6.5}$$

$$+\frac{0.75(8.5-6.5)}{8.5-5}+\frac{0.7(7-7)}{7-4.5}+\frac{0.95(9.5-8)}{9.5-6}+\frac{0.4(8.5-8.5)}{8.5-6}$$

$$\left.+\frac{0.4(9.75-8)}{9.75-8}+\frac{0.825(8.5-7.5)}{8.5-6}+\frac{0.55(9.5-6)}{9.5-5}\right)$$

$$=(1.256, 2.444)$$

Using Eq (20), the value of $\otimes R_i$ is calculated for MSSP_1 as $(0.314, 0.45)$.

Using Eqs (21) to (24), the values of $\otimes S^*$, $\otimes S^-$, $\otimes R^*$, and $\otimes R^-$ are calculated as (0.19, 0.6), (2.452, 4.604), (0.15, 0.32) and (0.6, 0.9).

Using Eq (25), the value of grey decision coefficient $\otimes Q_i$ for MSSP_1 is calculated as

$$\left(\frac{0.5(1.256-0.19)}{2.452-0.19}+\frac{(1-0.5)(0.314-0.15)}{0.6-0.15},\frac{0.5(2.444-0.6)}{4.604-0.6}\right.$$

$$\left.+\frac{(1-0.5)(0.45-0.32)}{0.9-0.32}\right) = (0.342, 0.419)$$