

## Using DEMATEL Method to Develop Conceptual Model for Evaluating Green Suppliers

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### **Abstract**

*Nowadays stakeholders and public awareness have increased the pressure on companies for environmental issues. Thus, green supply chain management (GSCM) seems vital for companies' environmental compliance and business growth. Companies continuously seek novel ideas and methods, that can enable them to obtain and/or maintain environmental sustainability. Greening the supply chain is one such innovative idea that rapidly spreads in the industry. The traditional internal measures, such as performing waste-reduction strategies, installing pollution control technologies, substituting hazardous-materials with environmentally friendly ones, are becoming less important as companies strive to find more innovative solutions. Accordingly, the main objective of the present study is to find interrelationship among green supplier criteria. For this to happen, we investigated experts' opinions through nominal group technique (NGT) to find out the interrelationship and causal preferences of the green supplier evaluation aspects using Decision-Making Trial and Evaluation Laboratory (DEMATEL) method. A numerical example demonstrates the application of the proposed model.*

**Keywords:** Green Supply Chain Management, Decision-Making Trial and Evaluation Laboratory (DEMATEL)

## Introduction

On one hand, the growing consciousness of environmental protection worldwide makes the green movement towards conserving the earth's resources and protecting the environment inevitable for enterprises. On the other, globalization has stimulated enterprises to enhance their environmental performance. Growing environmental importance has gradually incorporated into the overall institutional culture (Fahimnia et al. 2015; Salam 2008; Zhu and Sarkis 2006). Companies are under constant pressure to seek novel ideas and methods that can enable them to obtain and/or maintain environmental sustainability. Greening the supply chain is one such innovative idea that rapidly spreads in the industry. The traditional internal measures, such as performing waste-reduction strategies, installing pollution control technologies, substituting hazardous-materials with environmentally friendly ones, are becoming less important as companies strive to find more innovative solutions. Many leading companies have already obtained various positive internal measures (Fahimnia et al. 2015). Nowadays, the aim has started to shift toward involving environmental protection measures in all business value-adding operations: purchasing and in-bound logistics, production and manufacturing, distribution and out-bound logistics (Talaie-Khoei et al. 2011). Greening the supply chain is one of the fundamental principles environmental protection that is vital for prospering industrial ecosystems and creating value for firms (Bose and Pal 2012). Additionally, there is another reason why the greening of the supply chain is being widespread within industry. Many world-class companies now perceive that

customers and other stakeholders do not differentiate between a company and its suppliers. According to Bacallan's study (2000), "although they may have nothing to do at all with the problem, companies are often held accountable for the labor practices and the environmental liabilities of their suppliers". Thus, greening the supply chain assists companies to keep away from potential environmental problems that might emerge with their suppliers and that in turn could endanger their own environmental performance. Problems emerging for organizations can extend from actual business continuousness and heavy responsibility issues to intuitive problems of possessing "dirty" partners (Sarkis 2006). Although there has been a body of literature evaluating suppliers in the context of green supply chain, an explicated conceptual model that ranks different suppliers from the green supply chain perspective has been largely ignored. Mingbo and Dan (2009) suggested a model that states the criteria of green suppliers' performance. However, in the model a decision making tool lacks the relationships. Therefore, the main objectives of this paper is first to come up with the relationships for the model of Mingbo and Dan (2009) and then, to determine the significance of interrelationships among criteria to evaluate supplier performance. Multi Criteria Decision Making (MCDM) assists organizations and supply chain managers to make more effective decisions (Chai et al. 2013). To promote this area of research and to help further integrate sustainability discussion into the suppliers' evaluation modeling area, we model the supplier evaluation problem in green supply chain context with a group decision making approach which is a Decision making trial

and evaluation laboratory (DMATEL) method. Since, DMATEL simplifies the complex criteria and recognizes interrelationship influences between factors of green suppliers, we have utilized it to determine the significance of the relationships in our conceptual models.

The rest of this paper is organized in the following way: the first section presents literature review about green supply chain; the following section presents the proposed conceptual model; the third section presents the application of DMATEL; the fourth section demonstrates the proposal using a numerical example; and the last section discusses the results.

### Literature Review

With government regulations and growing public consciousness in environmental protection, companies today definitely cannot neglect environmental issues if they want to survive in the global market. Besides following the environmental regulations for selling products in particular countries, companies are required to execute strategies to diminish the environmental damage of their products. The combination of environment, economic and social performance to reach sustainable development is a prominent business challenge for the new century (Verghese and Lewis 2007). Some possible definitions of Green Supply Chain Management (GSCM), known as a principal of achieving sustainable business development, have been presented over the last decade, include:

1. Green supply applies to the way in which innovations in supply chain management and industrial purchasing may be taken into consideration in the

context of the environment (Green et al. 1996).

2. Environmental supply chain management is composed of the purchasing function's involvement in activities that comprise reduction, recycling, reuse and the substitution of materials (Narasimhan and Carter 1998).
3. GSCM is the practice of monitoring and enhancing environmental performance in the supply chain (Godfrey 1998).

In literature, several researches assessing environmental performance of suppliers and supply chains have been reported (Govindan et al. 2015). Enarsson (1998) suggested a fish bone diagram to assess environmental features of suppliers. Humphreys and colleagues (2003a) applied case-based reasoning to evaluate environmental performance of suppliers. Bai and Sarkis (2010) employed grey system and rough set methodologies to merge sustainability into supplier selection. Further, Humphreys et al. (2006) applied dynamic fuzzy membership functions to evaluate environmental performance in the supplier selection process. Handfield et al. (2002) applied environmental criteria in AHP for supplier assessment. Tuzkaya and colleagues (2009) demonstrated a hybrid fuzzy multi criteria decision approach for measuring environmental performance assessment of suppliers. Zhang et al. (2003) suggested a fuzzy multi-agent decision-making strategy for environmentally aware supplier management. Noci (1997) suggested „green“ vendor rating systems for evaluating of supplier's environmental performance. Walton et al. (1998a) presented an approach for greening the supply chain by involving suppliers into environmental management processes. Lee and co-workers (2009)

demonstrated a green supplier selection model for high-tech industry employing Delphi method and fuzzy extended analytic hierarchy process. Lu et al. (2007) suggested a multi-objective decision analysis to use environmental tenets in order to assess green supplier at various levels of supply chain. Humphreys and colleagues (2003b) presented multi-stage framework for combining environmental criteria with supplier selection process and examining suppliers' environmental performance.

Various multinational enterprises are investing in researching and developing green products, constructing standards avoiding the use of hazardous substances, and instructing suppliers to deliver products that are free of hazardous materials at all levels of the supply chain. Therefore, GSCM has appeared as a strategy for several leading companies in the electronics industry, comprising Dell, HP, IBM, Motorola, Sony, Panasonic, NEC, Fujitsu, and Toshiba (Zhu and Sarkis 2006). This phenomenon indicates that companies start to realize that environmental consciousness can be an origin of competitive advantage (Bose and Pal 2012; Walton et al. 1998b). In addition, GSCM can encourage efficiency and synergy among business partners and their lead corporations, and assist to improve environmental performance, diminish waste and acquire cost saving (Rao and Holt 2005). In the present business environment, procurement has turned to be crucial in creating value-added contents of products and determining factor to ensure the profitability and survival of a company. The purchasing process gets more complicated when environmental and social issues are involved (Lee et al. 2009). In this context, green supplier evaluation is appearing more

essential for effective green supply chain management (Govindan et al. 2015). Bala and colleagues (2008) investigated five cases of supplier greening at Universitat Autònoma de Barcelona and indicated that collaboration and partnerships with suppliers may promote the introduction of green supply and guarantee the prosperity of a green initiative in a public organization. Jabbour and Jabbour (2009) studied Brazilian companies and found out that those with more advanced environmental management system select more formal procedures for choosing environmentally friendly suppliers than the ones with less advanced systems.

### **An Analytic Network Supplier Evaluation Model for Green Supply Chain**

Constructing an operative supplier evaluation model is one of the crucial challenges supply chain managers face. To evaluate potential suppliers, it is required to develop a set of relevant selection criteria. In this sense, quality, cost efficiency, delivery, information, volume, lead-time flexibility, and customer service level are the traditional criteria (Yeh and Chuang 2011). The Analytic Network Supplier Evaluation Model for Green Supply Chain, proposed in this study, suggests that the supplier evaluation criteria fall into six dimensions: competitive pricing and cost, reliability, production capability, service, environmental performance and pollution control. They are examined below and shown in Fig.1. The hierarchy model of green supplier evaluation is shown in figure 1 which is adapted based on Mingbo and Dan (2009).

### **Proposed Method**

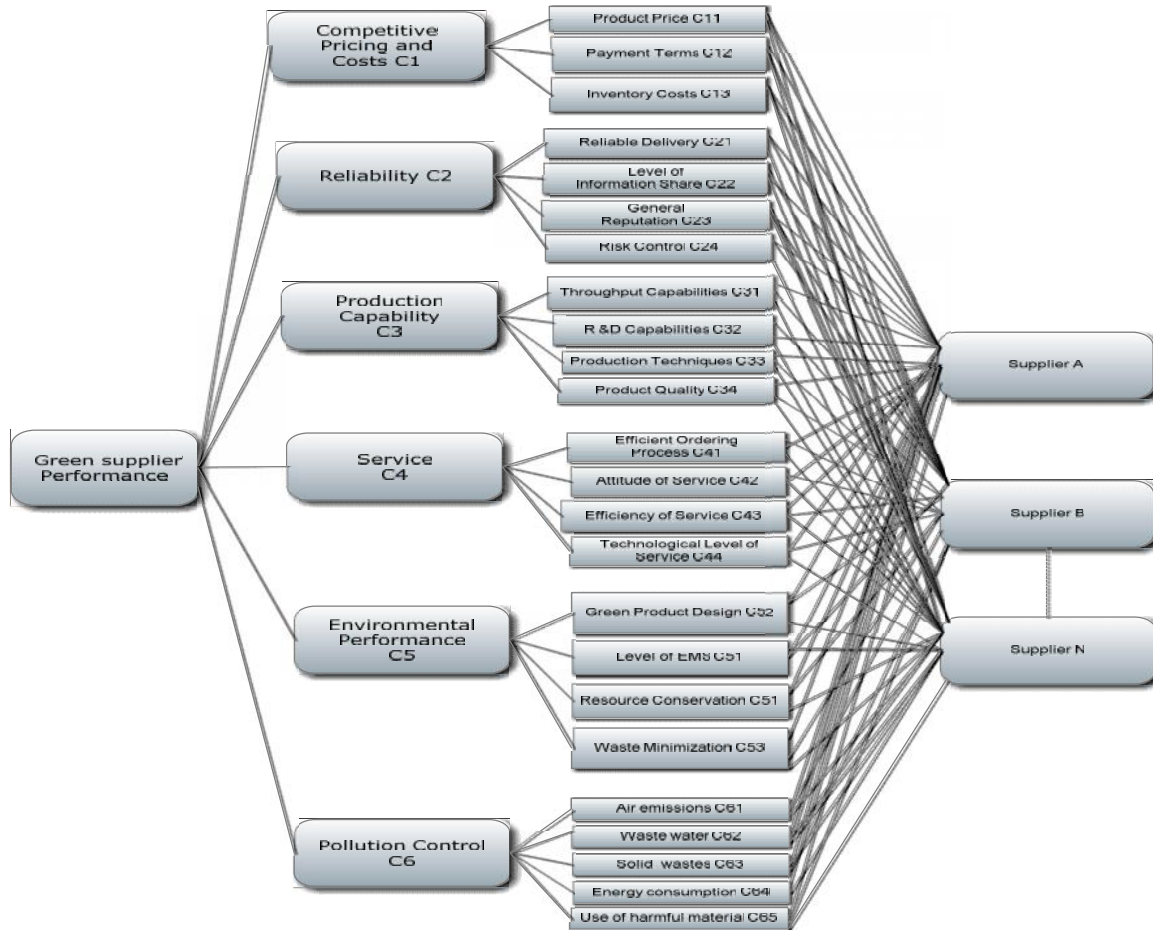
The current research is devoted to the development of a conceptual model for green supplier evaluation using DEMATEL. The model is aimed to help companies and supply chain managers to adapt to uncertainties and complexities in the real world, and to find a suitable tool for evaluating and controlling the green suppliers through different approaches. The green supplier evaluation methodology proposed in this study has three main steps:

1. Establishing and analyzing the sustainable criteria for supplier evaluation using experts' opinions with NGT. The expert panel consists of five managers and directors of environmental and supply chain departments from five different companies. In this step, the evaluation criteria for green suppliers will be collected through literature review and discussion with managers and eco-experts based on the analytic network supplier evaluation model for green supply chain which is shown in Figure 1.
2. Modeling DEMATEL for supplier performance evaluation in green supply chain context. In this step, DEMATEL for green supplier evaluation will be designed and insights into the method with some sensitivity analysis will be provided.
3. Validation of the model: A numerical example will be carried out to validate the new green supplier evaluation method. Due to the complexity of the decision-making process involved in green supplier evaluation, several aforementioned literature relied on some form of procedures that assign weights to various performance measures (Talaie-Khoei et al. 2012).

Our review shows that although some mathematical programming approaches based on multi-criteria decision making

methods have been used for the green supplier evaluation in different studies, they have a main weakness which is their inability to include interrelationships within the criteria in the model. It is often a difficult task for the decision maker to clarify these interrelations and causal preferences. The aim of this paper is to find out the interrelationship of the green supplier evaluation aspects using DEMATEL method.

DEMATEL is a sophisticated group decision making method for formulating and evaluating a structural model comprising the causal relationships among the complex and numerous factors (Lin and Lin 2008). From 1972 to 1976, this method was employed for the first time at Battelle Memorial Institute in Geneva to find out the complicated and interlaced problem group (Gwo-Hshiung et al. 2011). This methodology can verify interrelations between criteria and limit the relations which resonate the attributes of a system (Amiri et al. 2011). DEMATEL method has been developed based on the opinion that suitable employ of scientific research methods could improve understanding of certain problems and determine solutions with executive capability by a hierarchical structure (Lin and Lin 2008). Using DEMATEL method for evaluating and processing individuals' perceptions leads to individuals' personal notions being involved in complex problems (Gwo-Hshiung et al. 2011). The final product of DEMATEL process is a visual demonstration – mind map – based on which the respondent manages his/her actions regarding the world (Amiri et al. 2011) or adheres to the priorities stated in it (Gwo-Hshiung et al. 2011).



**Figure 1: The Analytic Network Supplier Evaluation Model for Green Supply Chain**

DEMATEL method consists of four steps which are delineated as follows.

### **Step 1: Making the direct-influenced matrix**

Finding the direct-relation (Average) matrix: At first we have five scales that determine the values of relationships between different factors according to the experts' opinion. Five scales are employed to measure the relationship between various criteria comprising:

- 0 = no influence,
- 1 = low influence,
- 2 = medium influence,
- 3 = high influence,
- 4 = very high influence

Then sets of the pair-wise comparisons in terms of effects and direction among criteria are provided by decision makers i.e. experts. Thereafter, the initial data can be achieved as a direct-relation matrix, which is a  $[n \times n]$  matrix A. Each element of  $a_{ij}$  is marked as the degree in which the criterion i impresses the criterion j.

**Step 2: Normalize the initial direct-relation matrix. By normalizing the average matrix A, normalized initial direct relation matrix D is obtained in the following formulate.**

Normalization is calculated applying the following equation. Note that each element

$x_{ij}$  of matrix X is maximum one and minimum zero.

$$K = 1 / (\max_{1 \leq i < j \leq m} \sum_{j=1}^m a_{ij}) \quad i, j = 1, 2, \dots, m \quad (1)$$

$$X = K \times M$$

**Step 3: Calculate the total-relation matrix. A continuous reducing of the indirect effects of problems beside the powers of matrix D, like to an engrossing Markov chain matrix, guarantees convergent solutions to the matrix inversion.**

By applying the following formula (2), the total-relation matrix will be calculated. Note that I is the  $m \times m$  identity matrix.

$$T = X(I - X)^{-1} \quad (2)$$

**Step 4: Generating a causal diagram**

Through Equation 3, the sum of rows and the sum of columns are separately marked as vector D and vector R. Afterwards, the horizontal axis vector (D+R), called ‘Prominence’, is created by adding D to R, which presents the relative importance for every criterion. Likewise, the vertical axis (D-R), called ‘Relation’, is generated by subtracting D from R, which may categorize criteria into two groups including cause and effect. In general, the positive (D-R) means the criterion lies in the cause group and the negative (D-R) means the criterion reveals the effect group. Hence, the causal diagram is achievable by mapping the dataset of the (D+R, D-R), revealing some insight for facilitating decision-making.

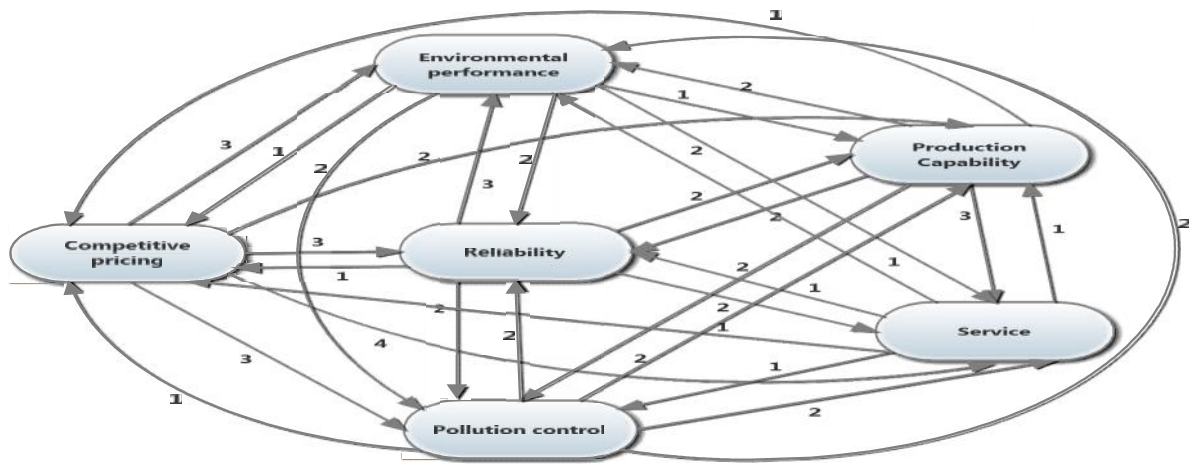
$$T = [t_{ij}]_{m \times m} \quad i, j = 1, 2, \dots, m$$

$$D = [\sum_{j=1}^m t_{ij}]_{m \times 1} = [t_{i.}]_{m \times 1} \quad (3)$$

$$R = [\sum_{i=1}^m t_{ij}]_{1 \times m} = [t_{.j}]_{1 \times m}$$

Numerical Example

Nominal Group Technique (NGT) is a method for making decision applicable among different group sizes, in order to speed making decision, as by a vote, but everyone's opinions are considered and taken into account. There was an interview with experts of green supply chain. It is vital to search out experts who will verify the relationships among the influential success factors of green supplier performance. Experts were asked to organize sets of pairwise comparisons in terms of impacts and direction among green supplier performance factors including six dimensions: competitive pricing and cost, reliability, production capability, service, environmental performance and pollution control. Hence, the initial information can be achieved as a direct-relation matrix, which could be a  $6 \times 6$  matrix A, where every element of  $X_{ij}$  is marked as the degree, within that element  $i$  influences the element  $j$ . At this stage, we can notice the relation among significant factors in every criterion. Causal diagram which incorporates horizontal axis (D+R) and vertical axis (D-R) is ready. Relative importance of every feature is shown in horizontal axis, referring to ‘Prominence’ similarity features. which are divided into cause and effect clusters in vertical axis and are called ‘Relation’. Besides, advanced causal relationships aspects are visualized into observable structural model by causal diagram. However, if (D-R) is negative, this facet lies in the effect group; alternatively, if (D-R) is positive, the facet lies in the cause cluster. The relative importance of criteria is set by the committee of professional decision makers. The relations among essential factors, which are proposed in modeling of green supplier performance are illustrated in Figure 1.



**Figure 1. The relationships in green supplier performance**

On the basis of step 2 and equation 1, normalized matrix of green supplier performance evaluation is depicted as follows (Table 1).

Then DEMATEL technique and total relationships matrix are applied to green supplier performance evaluation; important factors for green supplier performance evaluation are demonstrated in Tables 2

**Table 1. Normalized green supplier performance evaluation**

Normalized matrix	Competitive pricing	Reliability	Production Capability	Service	Environmental performance	Pollution control
Competitive pricing	0	0.2	0.1333	0.2667	0.2	0.2
Reliability	0.0667	0	0.1333	0.1333	0.2	0.1333
Production Capability	0.0667	0.1333	0	0.2	0.1333	0.1333
Service	0.0667	0.0667	0.0667	0	0.0667	0.0667
Environmental performance	0.0667	0.1333	0.0667	0.1333	0	0.1333
Pollution control	0.0667	0.1333	0.1333	0.1333	0.1333	0



**Table 2. Total relationships matrices for green supplier performance evaluation**

Criteria	Competitive pricing	Reliability	Production Capability	Service	Environmental performance	Pollution control	R
Competitive pricing	0.1459	0.4273	0.3333	0.5465	0.4525	0.4273	2.3328
Reliability	0.1635	0.1794	0.2659	0.3425	0.3665	0.2971	1.6149
Production Capability	0.1619	0.2911	0.1458	0.391	0.3082	0.2911	1.5891
Service	0.1182	0.163	0.1459	0.1272	0.1726	0.163	0.8899
Environmental performance	0.1454	0.2644	0.1875	0.3017	0.1623	0.2644	1.3257
Pollution control	0.1549	0.2815	0.2549	0.3247	0.2981	0.1639	1.478
D	0.8898	1.6067	1.3333	2.0336	1.7602	1.6068	
D+R	3.2226	3.2216	2.9224	2.9235	3.0859	3.0848	
D-R	-1.443	-0.0082	-0.2558	1.1437	0.4345	0.1288	

### Discussion, Conclusion and Future Work

In group decision making problems often complex criteria are encountered which either influence, called cause group, or are influenced by several other criteria, making the effect group. Improvement in one or two criteria does not necessarily result in the overall system improvement, since there is a dependence and feedback relationship among the criteria. To make an effective decision, first cause group criteria need to be recognized and improved, which leads to the improvement of the effect group criteria.

As discussed above, DEMATEL methodology was applied in this study to explore the interactions among multiple criteria, which filled the gap left by the traditional models. In fact, the traditional models set strategies by only considering direct effects or single directions of criteria (Horng et al. 2013).

Final results that indicate influence levels of each criterion in the system as well as on each other are presented in Table 2. On the basis of the 'D - R' values, the criteria are categorized into two groups as cause and effect groups. The criteria

Service, Environmental performance and Pollution control fall under the cause group for having positive 'D - R' values. The criteria having negative 'D - R' values are categorized as effect group criteria, which include criteria Competitive pricing, Reliability and Production Capability. The results of cause and effect analysis show that 'competitive pricing', which belongs to effect group, is the most important criterion in this group. This result is in line with the findings of Rao and Holt (2005) which shows that integrated green supply chain ultimately leads to competitiveness and improvement of economic performance.

Through the analysis of the 'R + D' values, it is also found that the criterion competitive pricing is the most important driver among all criteria. The result is supported by the argument that competitive pricing about GSCM benefits is necessary to elicit their commitment and support for implementation of GSCM. Without competitive pricing, it would be difficult to order required resources for GSCM implementation. In addition, competitive pricing provides an opportunity of preparing

the environmental policy of an organization and creating the GSCM implementation plan. Following the confirmation of competitive pricing, 'R + D' values of other criteria are investigated to evaluate their priorities. The criteria, according to their degree importance were identified as Reliability > Environmental performance > Pollution control > Service > Production Capability. The result demonstrates that environmental performance as the third most important criterion is a suitable indicator for displaying companies adopting their supply chain to the GSCM. The results of the priority weight analysis of the criteria show that the 'Production Capability' has less influence on GSCM adoption. The facts show that production capability falls under effect group and there is a causal relationship between green design and production capability.

The results also illustrate that two of the criteria from cause group, 'environmental performance' and 'pollution control' are prioritized as the first and second key criteria, respectively. Two main reasons are suggested for higher influence of 'environmental performance' on GSCM adoption by the industries. First, societal concern for environmental protection saying that the regulations, stakeholder pressures and public awareness raised against the environmental impacts (Fahimnia et al. 2015; Sarkis 2006). Second, greening the different phases of the supply chain results in an integrated green supply chain, which eventually trigger competitiveness and economic performance (Bose and Pal 2012; Rao and Holt 2005).

### **Implications for Academics**

As public awareness of environmental protection has increased in the world, a huge

response to a green trend in conservation of natural resources and protection of the environment is risen (Xu et al. 2013). Eventually, this leads to the development and adoption of numerous environmental management techniques by companies from different industrial sectors around the world. Among all strategies, GSCM is becoming popular due to its ability of improving environmental performance of the entire supply chain. Previous studies demonstrated improvement in organizational performance through improved environmental supply (Walker et al. 2008). Although GSCM's importance and its benefits are well known, it has not been commonly accepted, due to a poor understanding of diverse influential factors of GSCM and interdependence. These influential factors can be divided in barriers and drivers. Barriers offer resistance to GSCM implementation (Muduli et al. 2013). Drivers differ according to their strength of influence on each other and on the entire system.

DEMATEL method was proposed in this research to evaluate the direct and indirect influences of GSCM criteria. DEMATEL technique helps the decision-making process to assess the causal relationship and the influence/strength of the target system criteria and displays the direct and indirect influences of criteria through a visual diagram (Govindan et al. 2016). In this study, the hierarchy model of green supplier evaluation adapted based on Mingbo and Dan (2009) and analyzed by DEMATEL method, includes six criteria. The analysis results were divided into two parts. First, the degree of influence of each criterion (priority weight) on the system was assessed and applied as a basis for ranking them. Second, the criteria were categorized as the

net dispatcher (cause group) criterion or net receiver (effect group) criteria. The cause group criteria not only have higher driving power of the entire system, but also a strong influence on the effect group criteria. Indeed, the improvement in criteria of the cause group will result in improvement in the criteria of the effect group. Therefore, the study finds that the environmental performance and pollution control as cause group criteria have great influence on competitive pricing and reliability criteria, according to the priority weight analysis. Since, DEMATEL simplifies the complex criteria and recognizes interrelationship influences between factors of green suppliers, this study has several particular contributions including:

- Determining the explicit criteria and sub-criteria and interrelationship between them regarding all factors of competitive pricing and cost, reliability, production capability, service, environmental performance and pollution control for balancing greening supply chain issues.
- Modeling the DEMATEL for determining interrelationship among criteria to evaluate supplier performance
- Developing a practical model in green supply chain context, which can help organizations and supply chain managers make decisions that are more effective.

### **Implications for Practitioners**

Using DEMATEL in this study provides an easier way to find the complexity of the decision-making problem through classifying the complex criteria into cause and effect groups, thereby helping to

facilitate decision-making. The managerial implications that extracted from this study are:

- Categorization of criteria into cause and effect group will assist the decision makers to determine the group of factors (cause group) requiring control and attention (Lin 2013). In fact, cause group criteria are difficult to move while those included in effect group are easily moved (Govindan et al. 2016). Additional prioritization of the criteria will assist the decision makers in identifying the criteria requiring improvement on a priority basis, which subsequently improves other criteria and the entire system.
- Table 2 and Fig 1 (cause and effect diagram) illustrated that competitive pricing is the most important criterion in the ranking. Obviously, it has the highest 'R' value which is an indication of the highest degree of influence allotted by it on other criteria and on the system (Akhilesh and Kamalakanta 2013).
- It has been shown that 'pollution control' is the fourth most significant criterion. It falls under the cause group category and has the highest driving power in this group due to its highest value of 'R'. Therefore, managers should concentrate on pollution control and environmental performance to improve GSCM performance. Furthermore, they should aim at formulating strategies that concentrate on fulfilling pollution requirements for enhanced environmental performance to balance economic and environment indicators (Wu and Pagell 2011).

### Limitations and Future Work

Analysis of GSCM criteria with DEMATEL method is performed using the judgment of few experts. However, for constructing a solid model, future studies should include a network base data envelopment analysis model. Although, some methods have been developed with a variety of formal modeling techniques, they may be limited due to different reasons. Multi Criteria Decision Making (MCDM) methods and decision support tools and methodologies can assist organizations and supply chain managers make decisions that are more effective. To

promote this area of research and to help further integrate sustainability discussion into the suppliers' evaluation modeling area, future studies might aim at modeling the supplier evaluation problem in green supply chain context with a novel approach which first was introduced by Charnes (1978). This approach employs Network Data Envelopment Analysis (DEA), a relatively new "data oriented" approach, for assessing the performance of a set of peer entities, named Decision Making Units (DMUs) and turning multiple inputs into multiple outputs (Cook and Zhu 2005; Kao 2009).

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