Green Supplier Evaluation and Selection Using Fuzzy Multi-Criteria Decision Making in Thai Tire Rubber Industry

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Abstract

Due to the challenges in increasing environmental consciousness, green supplier evaluation and selection has become an emerging issue. The objective of this paper is to propose a method for the evaluation and selection of green suppliers through an example in the Thai tire rubber industry. This study identifies seven key environmental criteria for assessing and selecting green suppliers in industry and introduces a successful implementation of Green supply chain management practices (GSCMP). The criteria have been sourced through extensive literature research and interviews with ten practicing industrial experts. The proposed methodology uses a Fuzzy Analytic Hierarchy Process (Fuzzy AHP) framework to weight the criteria and select the supplier with the best set of environmental performances. The fuzzy approach was chosen to accommodate the typical vagueness and subjectivity in any typical expert decision-making process. The real-world case study discusses the application of the method with three alternative suppliers in the tire rubber industry. The findings show that Environmental standard certification, Green technology capability and Pollution reduction capability can be identified as the first three most relevant criteria in the ranking of selection of green suppliers. To evaluate the proposed framework a case example of tire rubber manufacturing is selected. Results is depicted that supplier “S2” got the highest rank of candidate suppliers in overall criteria of study.
Keywords: Fuzzy Analytic Hierarchy Process, Green Supplier Selection, Thai Tire Rubber Industry

1. Introduction

Fallahpour et al. (2017) state that a supply chain comprises of various processes including production planning and control, sourcing in raw material, manufacturing, quality assurance and control, transportation, and management in backlog items. Eltayeb et al. (2011) have indicated that sourcing is a crucial point of the purchasing process in the supply chain, with its pivotal role in management of resource efficiency and cost reduction. Despite, the procurement challenge does not only concern the purchaser of the raw materials or the manufacturer of the products, but also to the suppliers of the raw materials. Supplier selection is, therefore, regarded one of the most strategic components in supply chain management of the company (Rao, 2012). Since environmental regulation such as WEEE, RoHS, and EuP directives were passed by the European Union (EU), similar regulations are coming into effect throughout the world. Today, GSCM has increasingly been adopted as a strategy by most of the major tire rubber producers in the automotive industry – including e.g. Bridgestone and Michelin (Tanielian, 2018). For instance, a green supply chain can introduce green manufacturing with an environmentally friendly design that helps in the manufacturing process waste reduction and GHG emission. A large number of companies aim to employ green supply chains through a Three Bottom Line (TBL) approach in material sourcing for sustainable and manufacturing production processes. Green manufacturers, today, increasingly focus on green supplier selection to maintain cost and help protecting the environment (Sarkis et al., 2015).

Green management in Thailand has been widely implemented in multiple sectors, including the tire rubber products sector. Rubber is a necessary raw material for producing products such as car tires. The demand from the automotive industry in Thailand has continuously risen (Chanchaichujit et al., 2016). Several manufacturers, who demand tire rubber for their manufacturing, are increasingly engaging in green supplier selection. Typically, the firm carefully assesses relevant green criteria when choosing a supplier of tire rubber. Nonetheless, utilizing environmental criteria probably won't be certainly in the final evaluation because the processes of the decision-making are complex and to increase any concern of profit loss including competitor's capability within the market. Besides, a green assessment may adversely impact between upstream and downstream in ambiguous condition, and finally the reputation of business results in negative impacts, particularly regarding corporate social responsibility.

There are a set of challenges in complex multi-criteria decision-making that apply to the selection of green suppliers in the Thailand rubber tire product industry. First, green criteria formerly utilized in the supplier selection in the rubber tire industry might not cover all relevant aspects and may not coordinate with a green supplier's practical operations. Traditional purchasing focuses on the classic time, price, quality, and transportation cost arguments whereas it often misses environmental aspects (Hamdan & Cheaitou, 2016). Traditional analysis only considers data without environment uncertainty. This lessens the efficiency of data analysis such as evaluating and ranking, specifically when arranging qualitative data (i.e., service minds, attitudes). Therefore, in the following, linguistic variables were used for expressing the way human express their thoughts through fuzzy characteristics; for example, by using linguistic terms such as 'equally important', 'weakly important', 'fairly important', 'very important 'and 'absolute important'. Finally, methods for determining the criteria weights in current green supplier selection did not examine the uncertainty and fuzzy characteristics raised during the decision making (Kilincci & Onal, 2011). Most of the studies merely employ basic principles when deciding the weights without a comprehensive analysis of each criteria's impact on final decision making results.

This study has three main contributions. Firstly, after attentive consideration of the environmental aspects concerning green supply chain position, the paper establishes seven criteria for green supplier selection, which can aid firms in the process of determining potential areas of enhancement for green suppliers, while preventing the potential risk of selecting unfavorable suppliers. Secondly, suppliers that pursue to 'go green' can apply the ranking result of relevant green supplier selection by focusing on each criterion. Suppliers may improve the long-term relationship with purchasers by encouraging their green practices as worthwhile contributions. Finally, this paper proposes an MCDM model based on fuzzy set theory for solving the problem in green supplier selection in an ambiguous environment, as well as selecting an appropriate green supplier.

2. Purpose

1) To determine the important weights of green criteria under vague environment

2) To evaluate and rank the potential green suppliers

3. Research Methodology

This section includes how to collect data, extract green supplier selection criteria and propose Fuzzy Analytical Hierarchical Process (F-AHP) which is applied to the example of the rubber tire manufacturing industry. The section also covers an explanation of the applicability of methods.

3.1 Data collection

To find out the green supplier selection criteria necessary for the assessment, top-management members with at least five years of experience within a company were interviewed through a questionnaire. The criteria were based on specification of the firm's green strategy and literature reviews. By applying purposive sampling, ten managers to combine the experienced group and each was expected to make a pairwise comparison of the decision criteria and alternatives.

3.2 Determining green criteria for selecting green supplier

A literature review survey and decision makers which rich expertise and background in green supplier selection for a tire rubber were conducted to decide which criterion would be used while selecting green suppliers, the experts needed to contemplate relevant criteria so that the evaluation and selection were well qualified. To provide full guidelines for decision-makers, explanations are shown in Table 1.

Table 1 Definition of criteria

Criteria	Definition	Authors
Green image (C1)	An environmentally friendly procedure has beneficial effects not only on the results of a supplier, but also on its reputation for customers and society.	Tuzkaya et al. (2009); Wittstruck & Teuteberg (2012); Girubha et al. (2016);
Green logistics (C2)	Sustainable transportation of products across the SC, such as the use of environmentally friendly transport and distribution, reverse logistics	Lee et al. (2009); Çebi & Otay (2016)
Pollution reduction capability (C3)	To evaluate the toxic substances and chemicals of a waste product	Öztürk & Özçelik (2014); Kannan et al. (2015); Sarkis & Dhavale (2015)
Green design of products (C4)	Eco-design, including measures to decrease the environmental impact of the design method over the entire life cycle of the products	Humphreys et al. (2003); Hsu et al. (2009)
Green technology capability (C5)	Development of alternative materials, machinery, products and techniques to enhance the life cycle of the product	Lee et al. (2009); Kuo et al., (2010); Buyukozkan &Cifci (2011)
Green packaging (C6)	Product packaging design that meets the recycling requirements	Lu et al., (2007); Govindan & Sivakumar (2016)
Environmental standard certifications (C7)	Introduction or acquisition of certification of environmental management systems (IS014001, ROUS)	Chiou et al. (2008); Uygun and Dede (2016); Jenssen & Boer (2019)

3.3 The proposed approach

Multi-Criteria Decision Making (MCDM) is a method that concurrently deals with multiple criteria and supports decision making by determining the best criterion according to a set of distinct criteria. This study introduced a Fuzzy set to direct concerns related to uncertainties in decision models (Chen & Chang 2011) including Fuzzy AHP.

3.3.1 Fuzzy Set Theory

Fuzzy set theory is helpful for solving issues involving uncertainties of bias (Watanabe, 1979). It was introduced by Zadeh (1965) and has been used for categorizing objects via a membership continuum. The level of the membership value ranges from 0 to 1 and is typically assigned to each relevant object.

Definition 1. A Fuzzy set $\widetilde{A}$ in x is defined by

$$\widetilde{A} = \{x, \mu_A(x)\}, x \in X$$

In which x is a symbolizes real value of the set X: $-\infty < x < +\infty$ and $\mu_A(x)$ is formed by the continual mapping between X and the closed interval [0, 1].

Definition 2. A Fuzzy number is a Fuzzy set in which the membership (Zadeh, 1974).

Triangular Fuzzy Numbers (TFN) are divided into three values: (1) the possible lowest value l, (2) the most promising value m, and (3) the possible upper value u. The TFN $\widetilde{A}$ is represented in the form of a membership function. $\mu_A(x)$

$$\mu_A(x) = \begin{cases} 0, x < 1 \\ \frac{x-l}{m-l}, l < x \leq m \\ \frac{u-x}{u-m}, m < x \leq u \\ 0, x > u \end{cases}$$

3.3.2 Fuzzy Analytical Hierarchal Process (Fuzzy AHP)

The Fuzzy AHP Algorithm was first developed by Buckley (1985) who used triangular fuzzy numbers to express linguistic variables used in the evaluation of alternatives. In his evaluations, Kilincci and Onal (2011) demonstrated that this technique could be applied from a different perspective by using triangular fuzzy numbers. This study is based on the Fuzzy AHP algorithm model utilizing the geometric mean method (Buckley, 1985) to obtain criteria weights for the GSS problem. A mathematical expression of the procedure is given below (Chen, 2000).

Triangular fuzzy numbers (TFNs) and linguistic variables can be applied to opt the priority of each decision variable. The appropriate linguistic variables used by decision makers (DM's) to evaluate importance weight of criteria and alternatives according to these criteria are given in Table 2 (Wanga & Hua, 2008) .

1) Define TFNs (Triangular Fuzzy Numbers) to determine the importance of each criterion or alternatives in pairwise comparison matrix from linguistic terms.

Table2 Linguistic variables and Triangular Fuzzy Numbers.

Linguistic scales for importance	Triangular Fuzzy Scales	Reciprocal Triangular Fuzzy Scales
Equally important	(1, 1, 1)	(1, 1, 1)
Weakly important	(2, 3, 4)	(1/4, 1/3, 1/2)
Fairy important	(4, 5, 6)	(1/6, 1/5, 1/4)
Strongly important	(6, 7, 8)	(1/8, 1/7, 1/6)
Absolutely important	(9, 9, 9)	(1/9, 1/9, 1/9)
The intermittent values	(1, 2, 3)	(1/3, 1/2, 1/1)
	(3, 4, 5)	(1/5, 1/4, 1/3)
	(5, 6, 7)	(1/7, 1/6, 1/5)
	(7, 8, 9)	(1/9, 1/8, 1/7)

2) Construct pairwise comparison matrix by fuzzy numbers.

$$\widetilde{A} = \begin{bmatrix} 1 & \cdots & \tilde{a}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \cdots & \tilde{a}_{nn} \end{bmatrix} \text{ ; } \tilde{a}_{ij} \text{ is represented a triangular fuzzy value} \quad (1)$$

3) Compute the geometric mean of fuzzy values in each criterion.

$$\tilde{u}_{ij} = \left(\prod_{i=1}^{n} \tilde{a}_{ij}\right)^{1/n} \quad (2)$$

4) Find the fuzzy criteria weights.

$$\widetilde{w}_i = \tilde{u}_1 \text{ x } (\tilde{u}_1 + \tilde{u}_2 \ ... + \tilde{u}_n)^{-1} \quad (3)$$

5) Applying defuzzified values method by Chou and Chang [50].

$$M_i = (\text{l}\widetilde{w}_i + \text{m}\widetilde{w}_i + \text{u}\widetilde{w}_i)/3 \quad (4)$$

6) Normalized preference or weight values.

$$N_i = M_i / \left(\sum_{i=1}^{n} M_i\right) \quad (5)$$

4. Results

In this section, the empirical study presented in this paper illustrates how rubber tire companies have applied the proposed new approach to assess and select their green suppliers of tire products for manufacturing industry among seven criteria as shown in Figure 1. The company's name is given as 'ABC' for data confidentiality. The company is one of the major producers of automobile parts in Thailand. The company applies the environmental policy in its integral supply chain, including sourcing process and harmonious actions with all suppliers to strengthen green practices. ABC has listed three potential green suppliers, namely S1, S2, and S3.

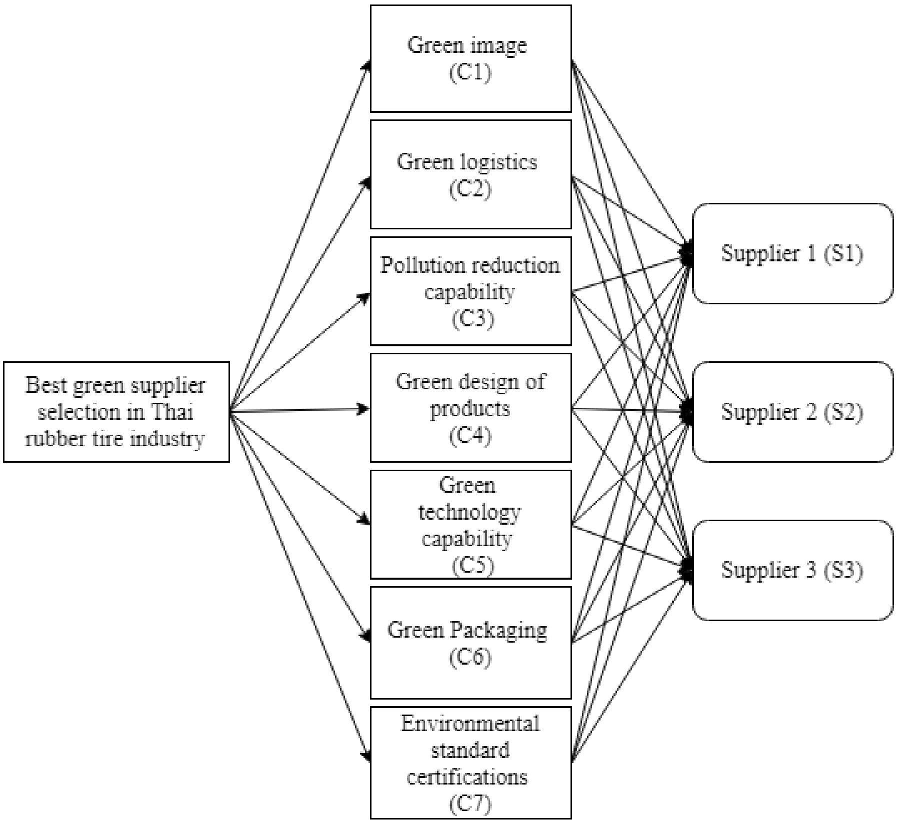

Figure 1 The hierarchical structure of green supplier selection problem

4.1 Calculating of criteria weights

According to their importance from top management level, the averaged pair wise comparison of the criteria is shown in Table 3.

Table 3 Pairwise comparison in each criterion

Criteria	C1	C2	C3	C4	C5	C6	C7
C1	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1,1,1)	(1/6,1/5,1/4)
C2	(2,3,4)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(1/6,1/5,1/4)	(2,3,4)	(1/4,1/3,1/2)
C3	(2,3,4)	(2,3,4)	(1,1,1)	(2,3,4)	(1/4,1/3,1/2)	(2,3,4)	(1/4,1/3,1/2)
C4	(2,3,4)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	(1/6,1/5,1/4)
C5	(4,5,6)	(4,5,6)	(2,3,4)	(2,3,4)	(1,1,1)	(2,3,4)	(1/6,1/5,1/4)
C6	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)
C7	(4,5,6)	(2,3,4)	(2,3,4)	(4,5,6)	(4,5,6)	(2,3,4)	(1,1,1)

After the pairwise comparison matrix by fuzzy numbers has been established, the geometric mean and fuzzy weight of each criterion are computed and had to be normalized according to Eq.(3), Eq.(4) as shown in Table 4.

Table 4 The geometric means and fuzzy weight of each criterion

Criteria	$\tilde{u}_{ij}$			$\tilde{w}_i$		
C1	0.331	0.394	0.500	0.029	0.044	0.072
C2	0.635	0.795	1.000	0.056	0.088	0.144
C3	1.000	1.369	1.811	0.088	0.152	0.261

Criteria		$\tilde{u}_{ij}$			$\tilde{w}_i$	
C4	0.635	0.795	1.000	0.056	0.088	0.144
C5	1.548	2.015	2.479	0.136	0.224	0.357
C6	0.371	0.456	0.610	0.033	0.051	0.088
C7	2.438	3.192	3.904	0.215	0.354	0.562
Total	6.959	9.016	11.304	0.029	0.044	0.072
Reverse	0.144	0.111	0.088	0.056	0.088	0.144
Increasing order	0.088	0.111	0.144			

Based on Eq. (4) and Eq. (5), defuzzify the weights obtained from fuzzy matrices (M_i) and Normalized fuzzy weight (N_i) are computed to show the criteria weights in Table 5.

Table 5 Priority weight and ranking for green criteria

Criteria	C1	C2	C3	C4	C5	C6	C7
$\boldsymbol{M_i}$	0.048	0.096	0.167	0.096	0.239	0.057	0.377
$\boldsymbol{N_i}$	0.045	0.089	0.155	0.089	0.221	0.053	0.349
Ranking	7th	5th	3rd	4th	2nd	6th	1st

It can be observed from Figure 2 that the weight of criterion C7 (Environmental standard certifications) has the highest importance (34.9%), followed by C5 (Green technology capability) 22.1% and C3 (Pollution reduction capability) 15.5%. While C1 (Green image) has the lowest importance among the seven criteria.

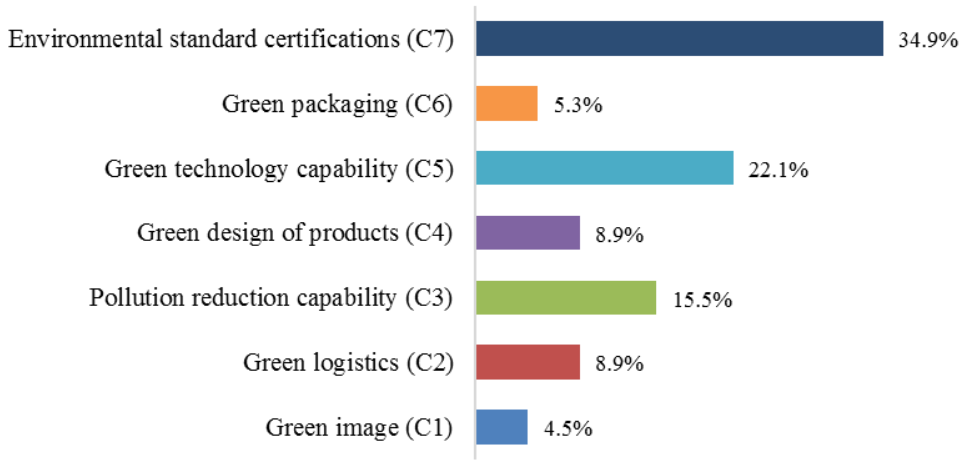

Figure 2 Bar diagram of weights of green criteria

4.2 Determining the ranking of green suppliers

From the proposed methodology, at first, experts were requested to give their opinion on the pairwise comparison matrix based on each supplier between criteria. For instance, pairwise comparison of suppliers with respect to C1 criterion (Green image) was examined and the following Table 6 was achieved.

Table 6 Comparison matrices on each supplier in C1 (Green image) criteria by expert

Supplier	S1	S2	S3
S1	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)
S2	(2,3,4)	(1,1,1)	(1/4,1/3,1/2)
S3	(1,1,1)	(2,3,4)	(1,1,1)

Like in the criterion calculation methodology from Eq. (2) to (5), the fuzzy weights of the suppliers for each criterion (M_i) and normalized values (N_i) values are summarized in Table 7.

Table 7 Averaged and normalized relative weights of each supplier with respect criterion

Criteria	C1		C2		C3		C4		C5		C6		C7	
Supplier	M	N	M	N	M	N	M	N	M	N	M	N	M	N
S1	0.230	0.223	0.656	0.597	0.166	0.151	0.656	0.597	0.632	0.575	0.656	0.597	0.117	0.107
S2	0.336	0.325	0.222	0.202	0.466	0.424	0.222	0.202	0.154	0.140	0.222	0.202	0.691	0.629
S3	0.466	0.452	0.222	0.202	0.466	0.424	0.222	0.202	0.312	0.284	0.222	0.202	0.289	0.263

By using Table 5 and Table 7, individual scores of each supplier for each criterion are presented in Table 8.

Table 8 Total results for each alternative according to each criterion

Criteria	Scores of suppliers with respect to related criterion			
	Weights	S1	S2	S3
C1	0.045	0.223	0.325	0.452
C2	0.089	0.597	0.202	0.202
C3	0.155	0.151	0.424	0.424
C4	0.089	0.597	0.202	0.202
C5	0.221	0.575	0.140	0.284
C6	0.053	0.597	0.202	0.202
C7	0.349	0.107	0.629	0.263
Total		0.336	0.377	0.287
Ranking		2nd	1st	3rd

The result of Table 8 show that Supplier 2 (S2) is the most preferable supplier (37.7%) over Supplier 1 (S1) 33.6% and Supplier 3 (S3) at 28.7% in the Thai rubber tire industry, respectively.

5. Discussion

Although the growing number of literature on green suppliers in recent years, there is limited research existing on tire rubber enterprises in Thailand. Even, the criterion for evaluating and identifying green vendors is inaccurate and needs to be improved. After comprehensive literature reviews and consultations with some specialists in this industry, a criterion including green (environmental) dimensions and green supplier selection problem model has been proposed. Among the seven criteria, environmental standard certifications obtain the primary weight (0.349), and green technology capability (0.221) is ranked in a second alternative, followed by pollution reduction technology (0.155), green design of products (0.089), green logistics (0.089), green packaging (0.053) and green image (0.045). Most experts in the case regard that the environment criteria of suppliers should first be reflected in their environmental management system, which corresponds to Guo et al. (2017), HM Wang Chen et al. (2016) and Jafarnejad et al. (2012).

6. Conclusions

Currently, rising concern is paid to the selection of a supplier accustomed the evidence that the organization of long-term partnership with a stable supplier can alter a cutback in the total production costs and embracing a competitive market. Considering the fact, that tire manufacturing processes are very complex, the tire manufacturer’s specifications for green suppliers can are getting increasingly complicated. To handle the uncertainty and incompleteness in green supplier assessment, this study has proposed a Fuzzy AHP approach for a tire rubber firm for the selection of the most appropriate supplier in Thailand. The results gathered by the applied methodology show that the seven essential criteria for the selection of suppliers are: green image, green logistics, and pollution reduction capability, green design of products, green technology capability, green packaging and environmental standard certifications. These criteria were used to identify the best supplier among three suppliers to overcome the challenge in selecting a green supplier for a tire rubber company in Thailand. As the result of the case study it is seen that the second supplier outperforms the others.

7. Recommendations

As for further research, we have the following recommendations. First, the final ranking results of green suppliers provided by the proposed model are greatly dependent upon decision makers’ subjective evaluations.

Therefore, we can increase the number of decision makers in the green supplier selection to mitigate this problem. Second, other MCDM techniques under fuzzy environments and hybrid models combining different methodologies incorporating the strong sides of each can be performed to solve this problem. In addition, their results can be compared with one of our proposed methodologies. Lastly, it may be clear that social aspects in emerging economies is a subject that benefits and requires further study.

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