Sustainable Supplier Selection Using the Fuzzy Multi-Attributive Border Approximation Area Comparison (F-MABAC) in Chemical Industry

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Abstract

The rapid growth of the industry in today's competitive environment has increased competition among companies. In order to gain business competitiveness, companies strive to focus on fulfilment of customer expectations of higher quality, lower prices, shorter lead times, and less environmental impact. Sustainability is an organization's ability to make decisions in real-time without an adverse impact on the future state of the environment, society and business stability. Since the production of most chemicals is highly hazardous and has the potential to cause irreversible environmental damage and have a negative impact on public health, safe and sustainable production is the main dictum for the development of sustainable chemical enterprises. Therefore, this paper addresses this issue by proposing a multi-method and multi-criteria decision-making framework for SSS in the chemical industry. Based on the specific characteristics of the chemical industry, this study uses AHP to analyse the economic, social, and environmental dimensions. Finally, this study will use Fuzzy MABAC to analyse alternatives. The proposed approach and decision-making model can help supply chain managers in the chemical industry to select more sustainable suppliers, respond quickly to market demands, and maintain high competitiveness in the market.

Keywords
Supplier Selection, Sustainability, Fuzzy MABAC, AHP and Chemical Industry.

1. Introduction
The rapid growth of the industry in today's competitive environment has increased competition among companies. To gain business competitiveness, companies try to focus on customer expectations of higher quality, lower prices, shorter lead times, and less environmental impact (Azadnia et al., 2015). Due to this competition, companies are trying to improve the performance of their entire supply chain. Supplier selection is an important decision step in supply chain design to reduce purchasing costs, supply risks, and environmental impacts and increase the price competitiveness of companies (Azadnia et al., 2015; Kannan et al., 2013). The number of companies that are aware of considering environmental practices into their strategic proposals and operations is increasing (Sarkis, 2003). Not only, it has led companies to ensure safe practices such as pollution control, reuse, recovery, but also brought positive impacts, such as improvement of business and public image, attraction of environmentally conscious customers, and improvement of quality (Molamohamadi et al., 2013).

Sustainability is the ability of an organization to make decisions in real-time without adverse impact on the future state of the environment, society and business stability. As global awareness of the environment and sustainability continues to increase, governments are becoming more focused and societies are becoming more knowledgeable (Wu et al., 2021). Pressure from regulations and policies, consumers, non-governmental organizations, and market competitors have all led companies to adopt the concept of having a sustainable supply chain (SSC). Therefore, combining environmental, economic and social aspects to ensure sustainable development is a key strategic task for business organizations in recent years.

Since the production of most chemicals is highly hazardous and has the potential to cause irreversible environmental damage and negative impact on public health, safe and sustainable production is the main dictum for the development of a sustainable chemical company. In addition, the raw materials used in the chemical industry are characterized by diversity, considerable risk, and complicated operations (Yang et al., 2020). In addition, there are various security risks throughout the manufacturing and transportation process. Without a safe and sustainable supply chain, there will be huge irreversible losses.

In the chemical industry, each of the dimensions of the Triple Bottom Line (TBL) has different characteristics, namely

1. Economical: there is a relatively small cost/price difference due to the capital-intensive nature of most chemical production processes.
2. Social: there is greater uncertainty in decision making due to the high-risk attributes of the chemical industry.
3. Environment: there is an imperative in the chemical industry for carbon footprint tracking which creates complex relationships between supply chain partners (Wu et al. 2021).

There is a need to apply specific methods to analyse and evaluate each of the different dimensions of TBL separately. Moreover, upon completion, there is a need to integrate the analysis results from each of the different TBL dimensions to identify the most appropriate supplier.

1.1 Objective

The objectives of this study are described as follows:

1. Identifying and generating criteria and weighting criteria needed by companies in the Triple Bottom Line dimension
2. Analyzing the best alternative based on criteria using Fuzzy MABAC methods.

2. Literature Review

Partner performance affects downstream company performance (Duman et al., 2017). Suppliers play an important role in implementing *sustainable supplier selection* initiatives in achieving social, environmental and economic benefits (Wu et al., 2020). society, and business stability (Tirkolaee et al., 2020, Nikolopoulou & Lerapetritou, 2012) studies the literature on sustainable chemical processes and supply chain design, with a focus on energy efficiency, water and waste management. They summarize the opportunities for the future in a multi-objective optimization framework from a TBL (Tripel Bottom Line) perspective. Fallahpour, (2017) discusses the problem of *sustainable supplier selection* through the use of a questionnaire survey and obtains supporting results using case studies. To maintain sustainability in supply chain management (SCM), supplier selection and policy making are the most fundamental decisions (Cheraghalipour & Farsad, 2018).

Multi-criteria decision making (MCDM) used to evaluate the selection of environmentally friendly suppliers with methods such as the Fuzzy Analytical Hierarchy Process (AHP), MABAC ("Multi-Attributive Border Approximation Area Comparison"), WASPAS ("Weighted Aggregated Sum-Product Assessment") and TOPSIS. (Gupta et al., 2019)

Gupta et al, (2019) The value entered is fuzzy and only takes comparative (linguistic) forms such as low, very low, medium or large etc. Several researchers have applied subjective weighting methods such as AHP, modified digital logic (MDL) and digital logic (DL) methods, Simple Multi Attribute Rating Technique Exploiting Ranks (SMATER), Best Worst Method (BWM), Level Based Weight Assessment (LBWA). The Stepwise Weight Assessment Ratio Analysis (SWARA)

Analytic Hierarchy Process (AHP) is one of the Multi Criteria decision making methods that was originally developed by. Saaty (1980). This is a method for obtaining a ratio scale from pairwise comparisons.

The Multi-Attributive Border Approximation Area Comparison (MABAC) method was introduced by (Pamucar & Cirovic, 2015). The basic assumption in this method is to determine alternative distances from the border approach area. In fact, each alternative is evaluated and ranked by determining the difference between the distances (Alinezhad & Khalili, 2019).

3. Method

3.1. Analytical Hierarchy Process

Steps:

1. Decision modelling hierarchy and consists only of constructing hierarchies to analyse decisions
2. Pairwise Comparisons
   Pairwise Comparison matrix table is shown in Tables 1, 2 and 3 where, element A has B_1, B_2,…,B_n as a sub element of A. Therefore, the matrix A of n x n can be written as follows.

3. Weight priority derivation for criteria.

- Normalize the data

$$N = \begin{bmatrix} n1 = \dfrac{s1}{\sum_{t=1}^{n} Si} \\ n2 = \dfrac{s2}{\sum_{t=1}^{n} Si} \\ n3 = \dfrac{s3}{\sum_{t=1}^{n} Si} \end{bmatrix}$$

- Calculate Eigen Vector
  Maximum eigen vector can be obtained by using Software or manual, calculated the eigen vector from each pair-wise comparison matrix. Eigen vector is the weight of each element, this step is to synthetize the options in the priority assignment of elements at the lowest hierarchy level to achieve the goal.

3.2 MABAC

Steps:

1. The Normalized Decision Matrix

$$X = \begin{bmatrix} r11 & \cdots & r1j & \cdots & r1n \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r1 & \cdots & rij & \cdots & rin \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ rm1 & \cdots & rmj & \cdots & rmn \end{bmatrix} \quad ; i = 1, \ldots\ldots, m \quad j = 1, \ldots.., n$$

where rij indicates the normalized value of the decision matrix of ith alternative in jth attribute. This method, decision maker Given the normalized values of the decision matrix and the weight of the attributes [w_1, w_2,…,w_n].

2. The Weighted Normalized Decision Matrix

$$r_{ij}^* = \frac{rij - r_i^-}{r_i^+ - r_i^-};\ \ i = 1, \ldots.., m,\ \ j = 1, \ldots\ldots, n$$
$$r_{ij}^* = \frac{rij - r_i^+}{r_i^- - r_i^+};\ \ i = 1, \ldots.., m,\ \ j = 1, \ldots\ldots, n$$

where r_{ij}^* shown that normalized value of the decision matrix of ith alternative in jth attribute.

$$r_i^+ = \max(r1, r2, \ldots\ldots rm)\ \ and\ r_i^- = \min(r1, r2, \ldots, rm)$$

3. The Border Approximation Area Matrix
   The values of the border approximation area matrix are obtained from

$$g_j = \left(\prod_{i=1}^{m} r_{ij}\right)^{1/m} \quad ; \quad j = 1, \ldots\ldots, n$$

By determining the values of the border approximation area matrix, a n x 1 matrix is obtained.

4. The Distance from the Border Approximation Area

With respect to the amounts of the border approximation area matrix and the weighted normalized values of each attribute, the distance of the alternatives from the border approximation area is determined as in Eq.

$$q_{ij} = r_{ij} - g_j; \quad i = 1, \dots\dots, m, \quad j = 1, \dots\dots, n$$

5. The Total Distances from the Border Approximate Area.
   The total distances of each alternative from the border approximate area is determined as in Eq.

$$S_i = \sum_{j=1}^{n} q_{ij}\,; \quad i = 1, \dots\dots, m$$

6. The Final Ranking of Alternatives
   The amounts of the total distances of the alternatives from the border approximate area are determined from the previous stage in a descending order and the final ranking of the alternatives is made.

4. Data Collection

This study uses two types of data, namely:

1. Primary Data
   Primary data is data obtained directly from the source. The primary data for this research were obtained from procurement managers with at least 5 years' experience in the chemical industry, academics at the Indonesian University's Chemical Engineering department, and expert employees in industrial services. The data used comes from a questionnaire about the importance of criteria, pairwise comparisons, and supplier assessment.

2. Secondary Data
   Secondary data is data obtained from appropriate literature studies, such as journals, proceedings, books. In this study, secondary data is used to support the research hypotheses and statements in this study. This research conducted deductive and inductive studies as a literature review. Deductive studies are carried out to obtain relevant theoretical foundations and to test whether the theory is suitable or not. Then proceed with conducting an inductive study to obtain related information on previous research in order to position this research to show the uniqueness of this research (Table 1 and table 2).

Table.1. Alternatifs

Alternatif	Nama
Alternatif 1	PT Indoporlen Refractories
Alternatif 2	PT Saint Gobain
Alternatif 3	PT. Benteng Api Technic
Alternatif 4	PT. Makmur Meta Graha Dinamika

Tabel 2. Criteria Sustainable Supplier Selection

No	Kriteria	Sub-Kriteria	Source
1	Economic	Price	A,B,C,D,E,F,G,H
2		Quality	A,B,C,D,E,F,G,H
3		On Time Delivery	A,B,C,D,F,G,H
4		Technology Capability	I,J
5		Resilience management	I
6		Reliability	D,K,L
7		Innovativeness	D,K,L
8		Organization and Management	B,C,D

No	Kriteria	Sub-Kriteria	Source
9		Warranties and claim policies	M,N
10		Financial Position	D,F
11		Geographical Location	D,K,L
12		Communication System	M,K,O
13		Reputation and position in the industry	N,J
14	Social	Ethical issues and legal complaint	P
15		Rights of stakeholders	
16		Local community influence	I,O,Q
17		Human resource capability	R
18		Work safety and labor health	A,B,C,D,L
19		Reputation General	K,L
20		Information disclosure	A,B,C,D,L
21		The interests and rights of employees	J,L,S
22		Training Continuous	L
23		CSR	H,I
24		Production safety	Q,S,T
25		Employee benefits	C,T,U
26		Respect for the policies	A,B,C,L
27	Environment	Carbon Footprint	C,D,Q,V
28		Environmental competencies	A,B,J,M,N
29		Land and Water pollution management	C,T
30		green material and technology	W,X
31		environment management system	A,B,C,D,E,F,G,H
32		Energy consumption	I,J
33		Hazardous material management	C,F,J
34		Recycling/Reuse/Remanufacture	A,B,J,M,N
35		Environmental training	Y,Z
36		Eco-design	A,B,C,D,F,G,H

resources:

A Hashemi et al., 2015
B Galankashi et al. 2016
C Wu et al. 2016
D Puška et al., 2018
E Rabbani et al., 2019
F Sen et al., 2018
G Imran et al., 2020
H Sarkar et al., 2019
I Govindan et al., 2015
N Guo et al., 2009
O Rouyendegh and Saputro, 2014
P Tavana et al. 2016
Q Ahmadi et al. 2017
R Mehregan et al. 2014
S Mahdi Paydar et al., 2017
T Wu et al., 2020
U Yu et al., 2019
V Yadav et al., 2021

J	Lee et al. 2015	W	Awasthi et al., 2010
K	Vasiljević et al., 2018	X	Humphreys et al., 2006
L	Jafarzadeh Ghoushchi et al., 2017	Y	Shen et al. (2013);
M	Liao and Kao, 2011	Z	Teixeira et al. (2016)

5. Result and Discussion

In this research, 9 respondents from 3 different fields fill the survey and obtained 33 criteria used to analyse the selection of sustainable suppliers. Figure below is a graph showing the results of the weighting of each criterion from the questionnaire using the Analytical Hierarchy Process (AHP). Below will be showed the result of AHP (Table 3, Table 4 and Table 5).

Tabel 3. Calculations for λmax economic criteria

Mmult		Weight		Result
0,444		0,035		12,532
1,452		0,118		12,313
1,590		0,127		12,534
0,708		0,058		12,212
0,960	:	0,079	=	12,137
0,516		0,042		12,231
1,290		0,103		12,570
1,234		0,099		12,475
1,573		0,123		12,809
1,506		0,119		12,631
1,257		0,097		12,961

Tabel 4. Calculating for λmax social criteria

Mmult		Weight		Result
0,452		0,033		13,560
0,319		0,024		13,142
0,362		0,027		13,533
0,477		0,035		13,669
1,593		0,116		13,679
1,177	:	0,086	=	13,762
1,136		0,083		13,643
1,681		0,125		13,493
1,590		0,118		13,498
1,756		0,127		13,829
1,777		0,130		13,683
1,300		0,096		13,518

Tabel 5. Calculating for λmax environment criteria

Mmult		Weight		Result

0,471		0,042		11,174
0,319		0,029		10,955
0,473		0,041		11,400
1,731		0,157		11,052
1,251	:	0,110	=	11,389
0,721		0,065		11,114
1,581		0,140		11,314
1,926		0,166		11,595
1,679		0,143		11,765
1,232		0,108		11,462

After getting the results of the division, the next step is to find the λmax of the data, λmax is the average result of the result table, which is 12.49, then look for the consistency index using the following formula,

$$CI_{Economic} = \frac{12{,}491 - 11}{11 - 1} = 0.149$$

$$CI_{social} = \frac{13{,}584 - 12}{12 - 1} = 0.144$$

$$CI_{Lingkungan} = \frac{11{,}32 - 10}{10 - 1} = 0.147$$

CI value, the process is to determine the value of CR (Consistency Ratio). The formula used is,

$$CR_{Economic} = \frac{0.15}{1.51} = 0.091\ (\boldsymbol{Consistent})$$

5.

$$CR_{Social} = \frac{0.144}{1.48} = 0.097\ (\boldsymbol{Consistent})$$

6.

$$CR_{Lingkungan} = \frac{0.147}{1.49} = 0.098\ (\boldsymbol{Consistent})$$

The results show that the resulting CR value is ≤ 0.1, so the calculation consistency ratio is acceptable (consistent).

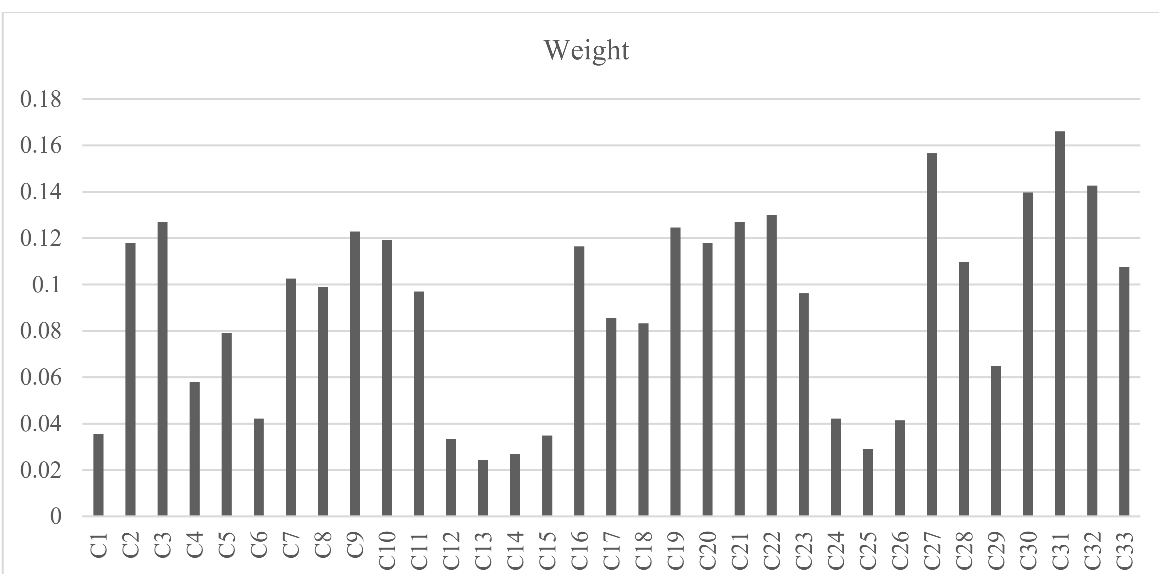

Figure 1. Graphic of criteria's weight

From the figure above (Figure 1) it can be seen that the first important criterion in the economic aspect to assess supplier selection is *delivery on time* with a weight of 1.127, *cost* is the second important criterion with a weight of 1.125, and the communication system is the third important criterion with a weight of 0.119. The first important criterion in the environmental aspect to assess supplier selection is *employee benefits* with a weight of 1.130, *production safety* is the second important criterion with a weight of 1.127, and *continuous training* is the third important criterion with a weight of 0.125. The first important criterion in the environmental aspect to assess supplier selection is *recycling/reusing* with a weight of 1.166, *green materials and technology is* the second important criterion with a weight of 1.157, and environmental training is the third important criterion with a weight of 0.143, this rating was obtained from a paired AHP which has been filled in by procurement experts at PT Teras Teknik Perdana.

In this study, there are 4 important alternatives involved in selecting suppliers at PT.Teras Teknik Perdana. Next will be explained about the use of the Fuzzy MABAC method by considering the weight of the criteria. The linguistic variable is carried out to determine the weight of the supplier's interests, the supplier weight is obtained from the Triangular Fuzzy Number (TFN) matrix and the criteria weight from AHP, the weights are shown in Table 6. Then the ranking results are carried out by calculating the final number of estimated border areas (Q), the highest final value is obtained PT. Saint Gobaint with a value of 1.21 and the lowest score was obtained by PT. Indoporlen Refractories with a value of 0.25. By using the MABAC fuzzy method based on the weight of the calculated criteria, PT. Saint Gobaint is the best supplier for PT.Teras Teknik Perdana.

Tabel 6. .Final result using Fuzzy MABAC

Alternatif	Nama	S			Result	Ranking
		L	M	U		
Alternatif 1	PT Indoporlen Refractories	0,259	0,171	0,171	0,025	4
Alternatif 2	PT Saint Gobain	1,566	1,574	1,574	1,211	1
Alternatif 3	PT. Benteng Api Technic	-0,619	-0,587	-0,587	0,158	2
Alternatif 4	PT. Makmur Meta Graha Dinamika	-0,555	-0,548	-0,548	0,131	3

6. Conclusion

This study aims are to create a model of sustainable supplier selection, using several criteria and then do pairwise comparisons to get the weight of each criterion. From 33 criteria researcher get the best supplier for PT. Teras Teknik Perdana is PT. Saint Gobaint with value of alternative is 1.21.

Based on what has been studied, this research still has many weaknesses in various ways, so it is expected that further studies related to the model of sustainable supplier selection can complement and improve this research.

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