



Research Article

A Hybrid Model for Green Supplier Selection and Order Allocation: DEMATEL, ANP, and Multi-criteria Goal Programming Approach

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A B S T R A C T

Increased competition in the industrial world forces companies to increase their competitiveness through Green Supply Chain Management (GSCM). The key to the success of GSCM is the selection of suppliers and the allocation of the proper order by taking into account environmental aspects. This decision involves several criteria and must also pay attention to the relationship between criteria. This study proposes a hybrid procedure to solve Green Supplier Selection and Order Allocation (GSSOA). The integration of Decision Making Trial and Evaluation Laboratory (DEMATEL), Analytic Network Process (ANP), and Multi-Criteria Goal Programming (MCGP) are proposed to solve this problem. The DEMATEL is used to calculate the relationship between criteria. Furthermore, the ANP is proposed to determine the weight of the criteria and supplier ranking. Finally, the MCGP method is offered for allocating orders based on priority suppliers. A case study on the food industry in Malang, Indonesia, was conducted to apply this procedure. The results showed that the low defects rate criterion is the most important compared to other criteria. The best supplier was successfully selected, and the order allocation was completed. Order allocation priority is to suppliers D, C, A, and B. This study also presents a sensitivity analysis for order allocation.

INTRODUCTION

In recent years, Supply Chain Management (SCM) has received attention from the world, both from researchers and industry players [1]. One part of SCM is supplier selection and order allocation. Supplier selection is an important activity in a company to gain a competitive advantage [2], [3]. A good supplier can reduce production costs and improve quality and customer satisfaction [4]-[6]. In addition, proper order allocation is also an essential aspect of the company. It can reduce purchasing costs and procurement risks [7]. Recently, the occurrence of climate change and global warming has raised global concerns about environmental issues. This problem certainly has an impact on the industrial world. In the study of Bloemhof-Ruwaard, et al. [8], supply chains are a significant source of waste and emissions. So that business people are under pressure from customers, regulations, government, and vendors to care about environmental problems [9], [10]. Therefore, companies compete to improve environmental aspects to maintain competitiveness in the global market [11].

Currently, Green Supply Chain Management (GSCM) is an issue that continues to receive worldwide attention. It aims to integrate

all aspects of logistics to produce sustainable company development by considering environmental elements [12]. Thus, the procurement of raw materials according to GSCM becomes the basis for supplier selection and order allocation [13]. This problem is called Green Supplier Selection and Order Allocation (GSSOA). In the GSSOA, priority supplier determination and order allocation must pay attention to environmental aspects [14]. One of the environmental aspects of this problem is fuel consumption in the transportation activity of delivery of raw materials. Most vehicles use non-renewable fuels as the primary energy of transportation. It is a concern for researchers because of the depletion of world oil reserves. Therefore, GSSOA needs to consider fuel costs in the allocation order decision. In addition, in GSSOA, the relationship between criteria needs to be investigated because the criteria depend on one another.

Experts have published several studies related to GSSOA. Shaw, et al. [15] researched the garment industry using the Analytical Hierarchy Process and Multi-Objective Programming methods. The Fuzzy technique for order performance by similarity to ideal solution (TOPSIS) and Multi-Objective Linear Programming (MOLP) methods were offered by Govindan & Sivakumar [16] in the paper industry. Furthermore, Kannan, et al. [17] proposed

the Fuzzy AHP, TOPSIS, and Multi-Objective Programming (MOP) methods in automobile manufacturing company. The fuzzy Analytic Network Process (ANP), fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL), and MOLP methods were developed by Bakeshlou, et al. [18] in manufacturing. In the same field, Lo, et al. [14] developed the Best Worst Method (BWM), Fuzzy TOPSIS, Fuzzy MOLP. There was also research on the food industry using the AHP, Delphi, Fuzzy Gray Relational Analysis, LP method by Banaeian, et al. [19]. Tirkolae [20] offered Fuzzy ANP, Fuzzy DEMATEL, TOPSIS, and MOP approaches to solve GSSOA problems in the central warehouse. The AHP, TOPSIS, and MOP methods were used by Mohammed et al. [21] with applications in manufacturing companies. AHP, TOPSIS, and MOLP fuzzy procedures were also offered by Hamdan and Cheaitou [22]. Other methods have also been proposed, such as the combination of MOLP and Data Envelope Analysis (DEA) [23], integration of fuzzy MOLP, fuzzy AHP, and fuzzy Topsis [24], and distributionally robust goal programming model and tractable approximation [25].

The criteria relationship needs to be investigated because it affects the weighting of the criteria. The GSSOA criteria's cause and effect relationships aid in developing maps that can be used to analyze and solve complex and interconnected problems. Impact relationship diagrams can also be used to identify critical criteria in complex structural systems. Unfortunately, we note that only two studies have addressed this issue, namely Bakeshlou, et al. [18] and Tirkolae [20]. Very limited published research on this issue. Hence, this study aims to propose a hybrid procedure to solve the GSSOA problem.

In this study, the environmental aspect uses the criteria of Eco-friendly packaging. This criterion needs to be investigated in relation to other criteria to determine the relationship with other criteria. In addition, in the allocation order, fuel transportation cost received less attention in the GSSOA issue. The transportation sector contributes the most significant carbon emissions in the world [26]-[28]. However, the goal allocation order does not only minimize fuel transportation costs. Other goals also need to be considered, such as supplier tardiness and minimization of defectives. Because it has several objectives, this problem is classified as a multi-objective problem. One of the most popular multi-objective models is Multi-Criteria Goal Programming (MCGP) [29].

This approach is proposed to solve problems characterized by multiple goals that may conflict with each other. The ultimate goal of all MCGP-based methods is to minimize unfavorable deviations from the goal. This method takes into account the expected value for the objective function and tries to minimize the number of deviations. Therefore, in this research, the proposed method is integrating DEMATEL, ANP, and MCGP. The relationship between criteria is assessed using The DEMATEL procedure. ANP is proposed to determine the weight of the criteria and supplier ranking. This procedure was proposed by Saaty and Vargas [30], which can assess the weight based on the dependency relationship. Furthermore, this study offers an MCGP method for determining order allocation. This study proposes six goals, and one of the goals is the minimization of transportation fuel costs.

METHOD

The Proposed GSSOA Procedure

This study proposes the integration procedure of DEMATEL-ANP and MCGP to solve the GSSOA problem. The framework of the proposed method is presented in Figure 1. Determining the criteria is the first step in resolving the GSSOA case. These are carried out through Focus Group Discussions (FGD). This study proposes three main phases in the completion of the GSSOA. The determination of the relationship criteria through DEMATEL is Phase 1. Then, in phase 2, the weighting of criteria and supplier ranking is calculated based on the ANP method. Finally, the last phase is order allocation with MCGP.

In phase 1, the DEMATEL method is proposed to assess the relationship between criteria. The steps of this method are based on the procedure proposed by Ranjbar et al. [31]. In determining the relationship between criteria, the FGD team assesses a scale of 0 (does not affect) to 4 (strongly affects). The results of the assessment questionnaire are presented in a direct matrix (B) as in equation (1). Furthermore, it is normalized by equations (2) and (3) to produce a normalized matrix (X) where s represents the normalization constant, where n describes the number of criteria. The normalization results are then used to determine the total relation matrix (T). It can be calculated based on equation (4). Equations (5) and (6) are applied to determine the values of D_i and R_j where D_i is the total row in the matrix T , and R_j shows the total column in the matrix T . They are used to obtain the prominence vector ($D_i + R_j$) and vector relation ($D_i - R_j$). The final step of the DEMATEL procedure is to determine the threshold value and Impact Relation Map (IRM). The threshold value (α) is the value used to determine whether the criteria have a relationship with other criteria. If the t_{ij} matrix value is greater than α , then the criteria have a relationship. These results are described in the IRM, which is used as a network in the ANP procedure. The illustration of IRM in matrix T is presented in Equation (7).

$$B = \begin{bmatrix} b_{11} & b_{1j} & b_{1n} \\ b_{i1} & b_{ij} & b_{in} \\ b_{n1} & b_{nj} & b_{nn} \end{bmatrix} \tag{1}$$

$$s = \frac{1}{\max \sum_{j=1}^n b_{ij}} \tag{2}$$

$$X = s \times B \tag{3}$$

$$T = (I - X)^{-1} \tag{4}$$

$$D_i = \left[\sum_{j=1}^n t_{ij} \right]_{n \times 1} \tag{5}$$

$$R_j = \left[\sum_{i=1}^n t_{ij} \right]_{1 \times n} \tag{6}$$

$$T = \begin{bmatrix} t_{11} & t_{12} & t_{13} \\ t_{21} & t_{22} & t_{23} \\ t_{31} & t_{32} & t_{33} \end{bmatrix} \tag{7}$$

In phase 2, this research proposes the weighting and ranking of suppliers using the ANP procedure. The proposed method is based on the proposed procedure of Saaty [32] and Yang, et al. [33]. In this phase, IRM results on DEMATEL are assessed using pairwise comparisons on a scale of 1 (equal importance) to 9 (absolutely more important). The results of the pairwise comparison assessment are presented in equation (8) which

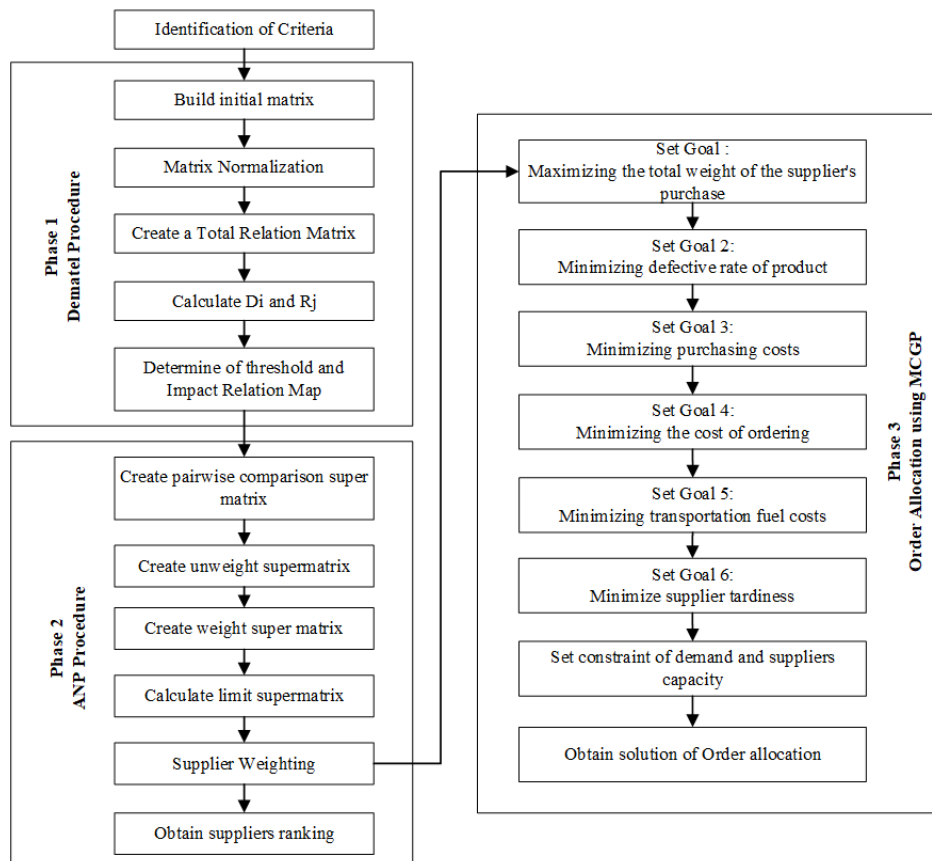


Figure 2. Design Parameters for Car Form Design

shows the unweighted supermatrix (A). Furthermore, the next stage is the weighted supermatrix. The initial T matrix is transformed into a new matrix α -cut total relation matrix ($T\alpha$). The $T\alpha$ matrix is illustrated in Equation (9) that is generated by assigning a value of 0 to the matrix value $<$ threshold value. The determination of the weighted supermatrix (A_w) is presented in equations (10), (11), and (12), respectively, where d_i is the number of rows in $T\alpha$. The last step of the ANP procedure is the calculation of the limit supermatrix. It is formulated in equation (13). The result of the limit supermatrix is the weight of each criterion and the weight of each supplier.

$$A = \begin{matrix} & C_1 & C_2 & \dots & C_n \\ C_1 & a_{11} & a_{12} & \dots & a_{1n} \\ C_2 & a_{21} & a_{22} & \dots & a_{2n} \\ C_3 & a_{n1} & a_{n2} & \dots & a_{nn} \end{matrix} \quad (8)$$

$$T\alpha = \begin{bmatrix} t_{11}^\alpha & t_{1j}^\alpha & t_{1n}^\alpha \\ t_{i1}^\alpha & t_{ij}^\alpha & t_{in}^\alpha \\ t_{n1}^\alpha & t_{nj}^\alpha & t_{nn}^\alpha \end{bmatrix} \quad (9)$$

$$d_i = \sum_{j=1}^n t_{ij}^\alpha \quad (10)$$

$$Ts = \begin{bmatrix} t_{11}^\alpha/d_1 & t_{1j}^\alpha/d_1 & t_{1n}^\alpha/d_1 \\ t_{i1}^\alpha/d_i & t_{ij}^\alpha/d_i & t_{in}^\alpha/d_i \\ t_{n1}^\alpha/d_3 & t_{nj}^\alpha/d_3 & t_{nn}^\alpha/d_3 \end{bmatrix} = \begin{bmatrix} t_{11}^s & t_{1j}^s & t_{1n}^s \\ t_{i1}^s & t_{ij}^s & t_{in}^s \\ t_{n1}^s & t_{nj}^s & t_{nn}^s \end{bmatrix} \quad (11)$$

$$A_w = \begin{bmatrix} t_{11}^s \times a_{11} & t_{1j}^s \times a_{12} & \dots & t_{1n}^s \times a_{1n} \\ t_{i1}^s \times a_{12} & t_{ij}^s \times a_{22} & \dots & t_{in}^s \times a_{2n} \\ t_{n1}^s \times a_{n1} & t_{nj}^s \times a_{n2} & \dots & t_{nn}^s \times a_{nn} \end{bmatrix} \quad (12)$$

$$\lim_{k \rightarrow \infty} W_w^k \quad (13)$$

The last phase is to determine the allocation order using MCGP. The supplier weight generated from ANP is used as one of the goals in MCGP. This study proposes six goals. Goal 1 and goal 2 maximize the total weight of supplier purchases and minimize defective goods from suppliers. Minimizing purchase prices from suppliers and minimizing ordering costs from suppliers becomes goal 3 and goal 4. Goal 5 and goal 6 are to reduce transportation fuel costs and supplier tardiness. In goal 5, transportation fuel costs consider the distance from the supplier, fuel consumption/km, and fuel price [34]. Moreover, tardiness time is a supplier's delay in delivering orders to the company [35]. In goal 1, the ANP supplier weighting results are used as a weight coefficient to maximize the total supplier purchase weight. The notations used in MCGP modeling on the GSSOA problem are as follows:

Parameters index

- i : index supplier, $i = 1, 2, 3, \dots, n$
- j : index goal, $j = 1, 2, 3, \dots, m$

Variables and parameters

- G_j : Goal j
- w_i : Supplier i weight (based on ANP)
- V_i : Product price on supplier i
- O_i : Cost of ordering to supplier i

- q_i : defect rate on supplier i
- K_i : Capacity of supplier i
- T_i : Tardiness time on supplier i
- Dis_i : distance of supplier- i
- Kpl : fuel consumption (liter/km)
- D : Demand of product
- cf : Fuel price (Indonesian currency, IDR.)
- C_i : Fixed cost of transportation
- X_i : order allocation on supplier i
- Y_i : binary number $\begin{cases} 1, & \text{if order is supplied by supplier } i \\ 0, & \text{otherwise} \end{cases}$
- Z : Goal deviation

Decision Variable

- d_j^+ : positive deviation for goal j
- d_j^- : negative deviation for goal j

The MCGP mathematical model for the GSSOA problem is presented as follows:

$$\text{Minimize } Z = \sum_{j=1}^n d_j^+ + d_j^- \tag{14}$$

Subject to:

$$\sum_{i=1}^n w_i \cdot X_i \cdot Y_i + d_1^- - d_1^+ = G_1 \tag{15}$$

$$\sum_{i=1}^n q_i \cdot X_i \cdot Y_i + d_2^+ - d_2^- = G_2 \tag{16}$$

$$\sum_{i=1}^n V_i \cdot X_i \cdot Y_i + d_3^- - d_3^+ = G_3 \tag{17}$$

$$\sum_{i=1}^n O_i \cdot X_i \cdot Y_i + d_4^- - d_4^+ = G_4 \tag{18}$$

$$\sum_{i=1}^n \left[\left(\frac{Dis_i}{Kpl} * cf \right) + C_i \right] Y_i + d_5^- - d_5^+ = G_5 \tag{19}$$

$$\sum_{i=1}^n T_i \cdot Y_i - d_6^+ + d_6^- = G_6 \tag{20}$$

$$\sum_{i=1}^n X_i = D \tag{21}$$

$$X_i \leq K_i \cdot Y_i \tag{22}$$

$$d_j^+, d_j^-, X_i \geq 0 \tag{23}$$

Minimizing the deviation from the goal is formulated in equation (14). Constraint (15) is Goal 1 which maximizes the total weight of supplier purchases. Constraint (16) is Goal 2 to minimize defective goods from suppliers. Goal 3 aims to reduce the purchase price from suppliers (constraint (17)). Constraint (18) is a goal 4 to minimize the ordering cost to suppliers. Constraint (19) indicates a goal 5 that minimize transportation cost. Constraint (20) represent Goal 6 that minimize the delay of supplier delivery. Constraint (21) shows the demand constraint. Constraint (22) is a supplier capacity limitation. Constraint (23) shows that the goal deviation (positive and negative) and order allocation to each supplier cannot be negative.

Case Study

The case study was conducted on the food industry in Malang, Indonesia. This company produces fermented soybean and fermented soybean chips with soybean as the primary raw material that is supplied from 4 suppliers. A Focus Group Discussion (FGD) was conducted by two experts involving supply chain and production managers and researchers. The team conducted two FGDs to determine the selection aspects and criteria of the GSSOA. The first FGD was used to determine selection aspects. The criteria used were selected in the second FGD. The selection aspects and criteria are compiled based on cases in companies that are supported by previous research. Furthermore, the team conducts deep discussions and analyzes the aspect and criteria to be used. The results of the FGD produced six selection aspects and 14 GSSOA criteria which are presented in Table 1. The company has four alternative suppliers (A, B, C, D) and a soybean demand of 150 kg in one production. Data on product prices, ordering costs, transport costs, defect rates, and delay times are presented in Table 2. The fuel

Table 1. GSSOA Selection aspects and criteria

No	Selection Aspect	Criteria	Criteria ID
1	Quality [36]	Consistent product quality [37]	C1
		Products according to specifications [36]	C2
		Low defect rate [18]	C3
2	Cost [15]	Ordering cost [16]	C4
		Product price [38]	C5
3	Delivery [16]	Product delivery time [39]	C6
		Quantity Accuracy [37]	C7
		Location of suppliers [40]	C8
		The completeness of the document	C9
		Replacement of defective products [18]	C10
4	Service [18]	Order quantity flexibility	C11
		Complaint procedure	C12
5	Flexibility [41]	Flexibility in changing delivery times	C13
		Eco-friendly packaging [42]	C14

Table 2. Suppliers data

Supplier	w_i	$q_i(\%)$	V_i (Rp/kg)	O_i (Rp)	C_i (Rp)	Dis_i (km)	Ti (hour)	C_i (kg)
A	0.2181	0.04	9,200	95,000	10,000	3.6	5	45
B	0.21766	0.03	9,500	102,500	10,000	0.47	4	50
C	0.26589	0.03	9,450	105,000	10,000	1	5	30
D	0.29835	0.02	9,350	92,500	10,000	4.2	2	50
GOAL	38.1502	4.2	1,402,500	395,000	49,455	-	16	-

Table 3. Assessment of the relationship between each criterion

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	0	1	1	0	2	0	0	0	0	0	1	0	1	0
C2	3	0	4	0	2	2	2	0	2	3	1	1	1	0
C3	4	3	0	0	2	0	3	0	1	3	2	0	1	0
C4	1	4	0	0	0	0	0	4	2	3	1	0	3	3
C5	1	4	0	1	0	0	0	1	2	3	0	0	3	4
C6	1	1	4	2	0	0	0	4	1	3	1	1	4	0
C7	2	1	0	1	0	1	0	1	1	3	3	1	4	0
C8	0	0	1	4	0	3	0	0	0	0	0	0	2	0
C9	1	1	1	1	1	1	1	1	0	1	1	2	1	0
C10	1	4	4	1	0	0	1	0	1	0	1	2	0	0
C11	0	0	0	0	0	0	2	0	1	0	0	0	1	0
C12	2	3	3	0	0	0	2	0	2	4	1	0	0	0
C13	0	0	0	0	0	3	1	3	2	1	0	0	0	0
C14	0	0	1	2	2	0	0	0	0	0	0	0	0	0

consumption (*Kpl*) in this case study is 10 km/liter, and the fuel price (*f*) is IDR 10,200. The results of the FGD assessment of the relationship between each criterion are presented in Table 3.

The results of the criteria relationship network based on DEMATEL are presented in Figure 2. Figure 3 shows the ANP network that was developed based on the criteria relationship. Three main clusters was proposed in the ANP network. Cluster 1 showed the comparison between the criteria and the best supplier. Cluster 2 showed the comparison of each criterion against other criteria based on IRM DEMATEL. Finally, cluster 3 was a pairwise comparison of criteria against each alternative supplier. The ANP method data processing was run with super decision software. In addition, order allocation optimization is completed with LINGO 11 software.

This study also presented a sensitivity analysis. It was used to determine changes in parameters that can affect the results. In this study, changes in demand were made to see the effect on the allocation of supplier orders. Demand was changed in $D = 120$, $D = 140$, $D = 160$, and $D = 170$. Changes in demand affect the *Gj* value of each existing goal.

RESULT AND DISCUSSION

Relationship Criteria based on DEMATEL

IRM results between criteria based on DEMATEL are presented in Table 4. The DEMATEL threshold value is 0.143. The IRM

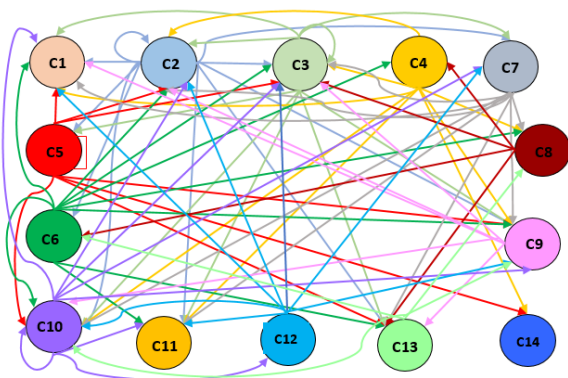


Figure 2. Design Parameters for Car Form Design

results show that the product criteria according to specifications (C2) are the criteria that have the most relationships. The criteria with the most correlation were low defect rate (C3) and product delivery timeliness (C6). It shows that the quality aspect is a critical aspect in GSSOA.

In contrast to previous research of Utama, et al. [43], their findings showed that the capability criterion is the criterion that has the most correlation. The results of this study follow the findings of research conducted by Li, et al. [44]. Their findings showed that the quality criterion is a criterion that has many influences on other criteria. It is reasonable because food products require good quality raw materials.

Consistent product quality criteria (C1) are categorized as dispatchers. It is because it shows that other criteria do not influence this criterion. On the other hand, the complaint procedure criterion (C12) is categorized as a receiver because it receives the most influence from different criteria. Criterion C12 is influenced by low defect rate (C3), consistent product quality (C1), the product according to specifications (C2), completeness of documents (C9), and accuracy of quantity (C7).

Criteria Weighting

The results of the weighting with ANP are presented in Table 5. The criterion that has the highest weight is the low defect rate (C3) of 18.26%. The second criterion is consistent product

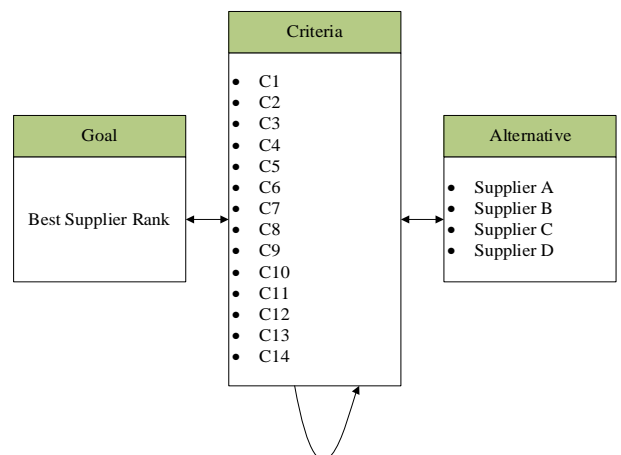


Figure 3. Network ANP on GSSOA problem

Table 4. IRM results between criteria based on DEMATEL

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C2	0,31	0,22	0,37	0,00	0,19	0,18	0,23	0,00	0,23	0,35	0,18	0,00	0,23	0,00
C3	0,32	0,30	0,16	0,00	0,17	0,00	0,24	0,00	0,16	0,31	0,20	0,00	0,20	0,00
C4	0,18	0,34	0,19	0,00	0,00	0,00	0,00	0,28	0,21	0,30	0,00	0,00	0,28	0,17
C5	0,18	0,34	0,18	0,00	0,00	0,00	0,00	0,00	0,21	0,30	0,00	0,00	0,26	0,22
C6	0,21	0,26	0,36	0,20	0,00	0,00	0,00	0,31	0,19	0,34	0,16	0,00	0,35	0,00
C7	0,20	0,19	0,15	0,00	0,00	0,00	0,00	0,15	0,16	0,28	0,22	0,00	0,30	0,00
C8	0,00	0,00	0,15	0,24	0,00	0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,21	0,00
C9	0,15	0,18	0,17	0,00	0,00	0,00	0,00	0,00	0,00	0,19	0,00	0,00	0,16	0,00
C10	0,21	0,35	0,34	0,00	0,00	0,00	0,17	0,00	0,16	0,19	0,16	0,15	0,00	0,00
C11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C12	0,25	0,32	0,31	0,00	0,00	0,00	0,22	0,00	0,20	0,36	0,16	0,00	0,00	0,00
C13	0,00	0,00	0,00	0,00	0,00	0,20	0,00	0,22	0,15	0,15	0,00	0,00	0,00	0,00
C14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Table 5 Results of weighting criteria

Criteria	Weight
Low defect rate (C3)	0.18263
Consistent product quality (C1)	0.12231
Product delivery time (C6)	0.09211
Quantity Accuracy (C7)	0.07693
The completeness of document (C9)	0.06979
Location of suppliers (C8)	0.06937
Products according to specifications (C2)	0.06644
Flexibility in changing delivery times (C13)	0.06512
Ordering cost (C4)	0.06259
Order quantity flexibility (C11)	0.05275
Product price (C5)	0.05206
Replacement of defective products (C10)	0.04645
Complaint procedure (C12)	0.02713
Eco-friendly packaging (C14)	0.01433

quality (C1) of 12.23%. Both of these criteria are classified on the aspect of quality. This result is different from previous research conducted by Shen, et al. [45], who also used the DEMATEL-ANP method. Their research results show that the most crucial criterion is material cost. However, the application is at a different company. In this study, the material cost aspect becomes the most critical aspect because the company focuses on minimizing the company's operational costs. By reducing material costs, the company can minimize operating costs so that the company's profits increase.

Table 6 Ranking of suppliers and order allocation

Supplier	Weight	Ranking	Order allocation (kg)
Supplier D	0.29835	1	50
Supplier C	0.26589	2	30
Supplier A	0.2181	3	45
Supplier B	0.21766	4	25

Table 7. Deviation value based on MCGP

	Goal 1	Goal 2	Goal 3	Goal 4	Goal 5	Goal 6						
Target	38.1502	4.2	Rp 1,402,500	Rp 395,000	Rp 49,455	16						
Actual	38.1502	4.25	Rp 1,402,500	Rp 395,000	Rp 49,455	16						
	d_1^+	d_1^-	d_2^+	d_2^-	d_3^+	d_3^-	d_4^+	d_4^-	d_5^+	d_5^-	d_6^+	d_6^-
	-	-	0.25	-	-	-	-	-	-	-	-	-

This study indicates that food products are highly dependent on the raw materials' quality. When the raw materials' quality is not appropriate, it can result in the expected product quality. The third highest third is the timeliness of product delivery (C6). This criterion produces a weight of 9.21%. This criterion is also important because if the supplier does not send raw materials on time, the company's production process will experience obstacles. It has an impact on the production and marketing, and sales aspects of the company.

The criterion that has the lowest weight is environmentally friendly packaging (C14). This criterion has at least a relationship with other criteria. In addition, environmentally friendly packaging is not a crucial issue for food companies. Food companies tend to prioritize the quality of product taste. Therefore, this criterion does not have a significant impact on product results. However, this criterion must be considered in supplier selection even though its contribution is less significant. Suppliers who have environmentally friendly packaging also contribute to fighting environmental problems.

Supplier Ranking

The results of supplier ranking are presented in table 5. The results show that supplier D is the supplier with the highest weight of 0.29835. The supplier with the second-highest weight is supplier C of 0.26589. supplier A occupies the third position with a weight of 0.21810. Finally, supplier B produces a weight of 0.21766. This result is reasonable because supplier D has a low defect rate and low prices compared to other suppliers.

Order Allocation based on MCGP

The results of order allocation based on MCGP are presented in Table 6. The results show that the most significant order allocation is for supplier D with 50 kg. Furthermore, orders from supplier A are 45 kg, supplier C is 30 kg, and supplier B is 25 kg. The deviation results from the MCGP optimization can be seen in Table 7. This result shows that one goal is not achieved. The

Table 8. Sensitivity analysis on changes in demand

	Demand = 120 kg			Demand = 140 kg			Demand = 150 kg			Demand = 160 kg		
	d_j^-	d_j^+	Goal Value	d_j^-	d_j^+	Goal Value	d_j^-	d_j^+	Goal Value	d_j^-	d_j^+	Goal Value
Goal 1	-	-	27,5859	1,497	-	34,5267	-	-	40,3268	-	-	42,5034
Goal 2	4,563	0,95	4,05	-	0,35	4,15	-	0,15	4,75	-	0,05	5,05
Goal 3	-	7250	1.125.000	-	15000	1.309.000	-	-	1.497.500	-	-	1.592.500
Goal 4	-	12500	302.500	-	-	290.000	-	-	395.000	-	-	395.000
Goal 5	-	-	35.171	-	-	38.435	-	-	49.455	-	-	49.455
Goal 6	-	3	14	-	-	11	-	-	16	-	-	16

Table 9. Allocation of orders on changes in demand

Supplier <i>i</i>	Demand = 120 kg		Demand = 140 kg		Demand = 160 kg		Demand = 170 kg	
	X_i	Y_i	X_i	Y_i	X_i	Y_i	X_i	Y_i
A	45	1	45	1	45	1	45	1
B	45	1	45	1	35	1	45	1
C	30	1	-	0	30	1	30	1
D	-	0	50	1	50	1	50	1

second goal is to minimize the number of defects that are not met. This goal produces a deviation value of d_2^+ above the target of 0.25. Based on optimization with linear programming partially, this optimization for G2 produces an optimal value of 4.2. However, optimization based on MCGP results in an actual goal value of 4.45. It shows that there is a deviation above the target of 0.25. In addition, the other goals meet the optimal goals. If linear programming optimization on goal 2 is carried out partially, the order allocation decision is 50 for supplier D, 30 for supplier C, 50 for supplier B, and 20 for supplier A. MCGP optimization with 6 goals results in an order allocation decision of 50 on supplier D, 30 on supplier C, 45 on supplier A, and 25 on supplier B. It can be seen that there is a difference in the allocation of order between partial optimization and MCGP for suppliers A and B. It causes a positive deviation in G2. It means that goal 2 is not in line with the target. The results of this study indicate that MCGP can perform optimization by minimizing deviations from contradictory goals.

Sensitivity Analysis

The sensitivity analysis to changes in demand is presented in Table 8, and the resulted order allocation for each supplier are presented in Table 9. These results indicate significant changes in minimizing purchasing costs. The purchase price increases as demand increases. Like a purchasing cost, the defect rate and the purchase's weight also increase when demand increases. It shows that changes in demand significantly impact the goal of purchasing cost, the defect rate, and the purchase's weight. This result is reasonable because the increase in demand goal purchasing cost, defect rate, and purchase weight also increase. In the order cost minimization goal, there are cost fluctuations in several demands. It is due to the order allocation for each supplier that changes with each demand. Small demand encourages companies to choose the supplier with the lowest order cost.

In the goal of minimizing transportation fuel costs, the sensitivity analysis results show that an increase in demand from 120, 140, and 150 kg increases transportation fuel costs. However, for demand 150, 160, and 170, transportation fuel costs are fixed. Furthermore, it shows that at demand ≥ 150 , all suppliers are allocated to fulfill demand. Therefore, the cost of transportation

fuel at demand ≥ 150 is fixed. However, on demand ≤ 150 , order allocation is made to 2-3 suppliers. Therefore, the cost of transportation fuel decreases.

In the tardiness time goal demand of 150 kg, 160 kg, and 170 kg, the total time is the same, which is 16 hours. As only in transportation fuel, when demand ≥ 150 , all suppliers are allocated to meet demand. Therefore, the delay from goal 6 is the same. While the 120 kg demand has a total time of 14 hours and 140 kg demand has a total time of 11 hours. It is due to the different order allocations in each demand, causing a supplier to be selected.

The deviation analysis in Table 7 shows that goal 5 (fuel transportation costs) is a goal that has neither positive nor negative deviation. Therefore, it indicates that the fuel transportation cost goal is a priority goal to be resolved in the GSSOA.

CONCLUSIONS

This study proposes integrating DEMATEL-ANP and MCGP to solve the GSSOA problem. Thirteen criteria are considered in the proposed GSSOA model. Based on the DEMATEL procedure, the criterion of product according to the specification (C2) have the highest level of influence compared to other criteria. Based on the ANP method, the most important criterion is the low defect rate (C3). Furthermore, we demonstrate that the proposed MCGP model can minimize the six goals' deviation by solving an industrial case from the food industry. While this study proposes to use crisp data, more in-depth investigation considering the fuzzy and/or stochastic nature in the model formulation can be a promising research agenda to enhance its applicability.

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