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Supplier Selection and Order Allocation of Recycled Plastic Materials: A Case Study in a Plastic Manufacturing Company

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Abstract

Supplier selection problem is one of the essential business activities related to sustainable development. This research conducted in a plastic manufacturing company that uses recycled Polypropylene (PP) type of plastic raw materials to reduce production costs and maintain the sustainability of the environment. The company faced some problems in supplier selection, which must be performed considering several criteria such as price, delivery, capability, and flexibility. In this paper, a decision-making process is proposed to solve the sustainable supplier selection in a multi-item and multi-supplier environment. This research proposes a model that combines the Best Worst Method (BWM), Technique For Reference Orders By Similarity To Ideal Solution (TOPSIS), and Multi-Objective Linear Programming (MOLP) to solve problems in sustainable supplier selection and order allocation. The results of this research can help managers to select suppliers and determine the optimal order allocation.

Keywords: Sustainable supplier selection, BWM, TOPSIS, MOLP, order allocation.

1. Introduction

In today's competitive industrial era, a company must make a good relationship with suppliers to ensure the availability of raw materials. The supplier selection problem included in the issue of multi-criteria decision making (MCDM), where companies have to select some suppliers based on their performance (see Ceby and Bayraktar [2]). Supply chain management strives to maintain long-term cooperation by using fewer but more reliable suppliers in the procurement of raw materials. Supplier selection is one of the most important components in supply chain management. Some criteria were used in supplier selection, including not only cost but also other quantitative and qualitative criteria (see Cengiz et al. [3]). The selection of suppliers is one of the most important decision-making problems because the selection of the right supplier can reduce costs, increase profits, reduce waste, increase customer satisfaction and also increase the competitiveness of a company (see Sureeyatanapas et al. [18]). The selection of suppliers is one of the most critical business activities that have a significant effect on product quality (see Cheraghalipour and Farsad [4]). Methods that supporting supplier selection with the same objectives were also reviewed in several research articles. In these literature, there are two types of supplier selection problems: single-item and multi-item problems with more than one supplier.

Rezaei et al. [17] proposed a new MCDM method called BWM to obtain criteria weights in a high-tech Chinese company that specialized in testing instruments. All of 87 suppliers considered were evaluated based on their capabilities and willingness criteria. Each supplier is assessed according to seven willingness criteria and eleven capabilities criteria. BWM has several essential features that make it a more robust and user-friendly method compared to most MCDM methods. The method requires fewer data with more reliable results, and also it does not use fractional numbers, so it is easier to understand by the Decision-Maker (DM). Oroojeni and Darvishi [14] and Tian et al. [20] used the combination of BWM and TOPSIS to solve the problem of supplier selection. Oroojeni and Darvishi [14] used the BWM method to rank the various criteria of green supplier selection in Khouzestan Steel Company (KSC) based on their green innovation ability. Afterward, Fuzzy TOPSIS is proposed to rank the various suppliers based on certain criteria for selecting the most effective suppliers among a set of alternative suppliers. Tian et al. [20] also revealed that compared to BWM, the classic AHP needs large amounts of pairwise comparisons to derive a consistent result due to its complex structure. Meanwhile, the classic TOPSIS only considers one single negative idea solution in selecting suppliers, which is more accessible to apply. The proposed method was then applied to a green supplier selection problem in the agri-food industry and followed by sensitivity and comparative analyses.

Govindan and Sivakumar [5] proposed the order allocation model based on green supplier evaluation. They suggested the fuzzy TOPSIS for supplier evaluation and selection, while MOLP was used to determine the order allocation to each of four paper manufacturing suppliers. Gupta and Barua [7] conducted three steps decision making procedure. In the first step, the criteria were selected through literature study and interview with the company manager. Next, the criteria weights were determined using BWM. In the last step, the suppliers were ranked and selected based on the overall criteria. Sureeyatanapas et al. [18] recommended the use of TOPSIS method to evaluate the best suppliers of the three alternatives of egg suppliers based on five criteria. The rank order centroid (ROC) method was chosen in the research to determine the weights of criteria to lessen the degree of subjectivity from the decision-makers as well as the uncertainty of the assignment of the weight. The criteria used were product quality, packaging quality, product price, delivery performance, and serviceability. Memari et al. [13] used an intuitionistic fuzzy TOPSIS method to evaluate and select the appropriate supplier based on nine criteria and thirty sub-criteria for an automotive spare parts company. Cheraghalipour and Farsad [4] developed two main objectives, to determine the right supplier and determine optimal allocation order based on several criteria used in supplier assessment, namely cost, quality, delivery, loyalty, technology, financial situation, service. BWM method was used to determine the weight of each criterion and preference of potential suppliers according to those criteria. Then the MILP model was used to solve the order allocation problem.

Evaluation and selection of suppliers in many industries and business are considered as an important activity (see Lo et al. [11]). The research aims to determine raw material suppliers for an electronics manufacturing company in Taiwan. To solve this problem, they proposed an integration of BWM, fuzzy TOPSIS, and FMOLP, involving qualitative and quantitative criteria. Guarnieri and Trojan [6] proposed a multi-criteria model in the supplier selection process of outsourcing activities in Brazil's textile industry. They performed three steps in the research: Copeland method was used to aggregate criteria in supplier selection. First, the AHP method was used to determine criteria weights of the criteria, and then ELECTRE-TRI method was used to classify the suppliers based on their performance.

In this research, we propose a method in supplier selection and how determining the optimal order allocation to the selected suppliers. The previous studies have discussed the integration of supplier selection and order allocation by applying the MCDM model. One of the most recent MCDM methods is BWM which used in this research because it will results more consistent comparisons in a particularly structured way compared to other MCDM methods. The BWM questionnaires are also easier to answer and have a higher degree of consistency than the popular AHP method. After completing the BWM, TOPSIS is applied in this study to determine each supplier's ranking for each raw material. The TOPSIS method has been widely used to solve supplier selection problems in real-world cases. Combining the weights obtained from the BWM and TOPSIS methods, allows us to integrate supplier performance into a ranking index, which is a more reliable strategy, with consideration of both qualitative and quantitative criteria. Finally, the MOLP model is developed to determine the optimal order allocation. The MOLP model makes it easy to come up with a compromise solution while considering multiple objectives and constraints in a dynamic environment. The results of order allocation are obtained by considering supplier performance and several goals to provide an optimal purchasing strategy.

The main contribution of this study is to evaluate and determine the optimal order allocation in a multi-item, multi-supplier environment based on a linear programming model. The selection of the selected supplier is expected to reduce costs and increase company competitiveness. In summary, the proposed model consists of three integrated components: (1) the BWM is used to obtain the weights of the criteria, which requires relatively fewer pairwise comparisons and can achieve consistent results more efficiently than AHP; (2) the model evaluates each supplier using the TOPSIS method; (3) the used of MOLP based on the results from TOPSIS method, to determine the optimal quantities that should be allocated to each supplier.

The rest of this paper is organized as follows. Section 2 describes the methodology of the proposed model. Section 3 presents a real-world application to demonstrate the feasibility and utility of the proposed model. Section 4 summarizes the discussion and provides a conclusion.

2. Methodology

This research was conducted through several steps. The first step involves identifying the criteria used in supplier selection by literature review. The resulted criteria are then discussed with the decision-maker in the company. We involved a manager and the head of procurement department in determining the criteria and sub-criteria used in selecting the suppliers. A questionnaire is developed, and the results of the questionnaire are used as the basis to determine the weight of each criteria using the BWM method.

In the second step, the TOPSIS method is used to evaluate each supplier so that each supplier's ranking is obtained based on their scores. In the next step, company data and the evaluation results of each supplier will be used as the inputs to the MOLP model that has been developed. The formulation of the MOLP model in this study refers to the research of Cheraghalipour and Farsad [4] and Lo et al. [11]. The optimization model involves two objective functions, using the transformation function scheme as suggested by Marler and Arora (2004) to solve the model. Finally, a sensitivity analysis is carried out to determine the impact of changes in the monthly demand for plastic ore raw materials to the decision variables and objective functions.

2.1. Supplier selection criteria

In this research, supplier selection criteria were collected from previous studies, as shown in Table 1. The criteria were assessed by three Decision Makers (DMs) that have been selected based on the results of company meetings. The decision-maker consists of three members who come from various departments, namely, procurement department expert (DM1), warehouse section (DM2), and production department manager (DM3). They have been appointed to involve in the supplier selection. Each decision-maker also assesses the performance of each supplier based on the approved criteria as shown in Table 2.

Table 1: A study of literature on sustainable supplier selection problem.

Reference	Criteria				Model Specification			Solution approach				
	Price	Delivery	Quality	Flexibility	Order Allocation	Single Item	Multi Item	BWM	TOPSIS	Other MCDM	Single Objective	Multi Objective
(Govindan and Sivakumar, 2016)	*	*	*		*		*		*			*
(Rezaei, Wang, & Tavasszy, 2015)	*	*	*				*	*				
(Zimmer et al., 2015)	*		*									
(Gupta and Barua, 2017)	*	*	*				*	*	*			
(Sureeyatanapas et al., 2017)	*	*	*			*			*			
(Cheraghalipour and Farsad, 2018)	*	*	*		*		*	*				*
(Lo et al., 2018)			*	*	*		*	*	*			*
(Tian et al., 2018)	*	*	*			*		*	*			
(Guarnieri and Trojan 2019)	*	*	*	*		*				*		
(Memari et al., 2019)	*	*	*	*			*		*			
(Oroojeni and Darvishi, 2020)	*		*	*			*	*	*			
This research	*	*	*	*	*		*	*	*			*

Table 2: Selected criteria and sub-criteria.

Criteria	Price (D1)	Delivery (D2)	Capability (D3)	Flexibility (D4)
Sub-criteria	Product price (C1)	On time delivery (C2)	Product quality (C4)	Flexibility of payment (C8)
		Accuracy of the order deliveries (C3)	Production capacity (C5)	Flexibility of changing orders (C9)
			Supplier reliability (C6)	Flexibility of delivery time (C10)
			Information of price changes (C7)	

2.2. Best worst method (BWM)

One of the most recent developed MCDM methods is BWM, a comparison-based method that results in more consistent comparisons in a particularly structured way compared to other MCDM method such as AHP (see Rezaei [16]; Gupta and Barua [7]; Cheraghalipour and Farsad [4]). The BWM questionnaires are easier to answer and have a higher degree of consistency than the popular AHP method (see Lo et al. [11]). The BWM method was first introduced by Rezaei [16] to solve multi-criteria problem decision-making. In the MCDM problem, several alternatives will be evaluated with certain criteria to choose the best ones. Based on the BWM method, the choice of the best criteria (e.g., very desirable, very important) and the choice of the worst criteria (for example, very little desirable, very little important) will be determined first by the DM. Furthermore, a comparison of the pairing is made between the best criteria and the worst criteria, along with other criteria.

Rezaei (2015) explained that the BWM method has advantages in the form of final weighting values, which can be more trusted because it provides a more consistent comparison when compared to the AHP method. The result of the comparison in the BWM method is always reliable, while in other MCDM methods such as AHP, the result is not always reliable. BWM is a vector-based method that needs fewer comparisons compared to AHP. The comparison matrix of AHP deals with fractional numbers, while BWM uses only integer number that makes it much easier to analyze.

2.3. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is one of the multi-criteria decision-making methods, which uses the principle that the chosen alternative must have the closest distance from the positive ideal solution and the farthest from the negative ideal solution. Euclidean distance is used to determine the proximity of the alternative distance to the optimal solution. The TOPSIS method is one of the well-known MCDM methods that considered positive and negative ideal solutions in decision making. The reason for this popular method is the fact that the TOPSIS method is easier to understand and simpler to implement compared with other outranking methods such as PROMETHEE and ELECTRE (see Sureeyatanapas et al. [18]).

The first step in TOPSIS is to build a normalized decision matrix based on the results of the assessment by the DMs. After that, a weighted normalized matrix is created by multiplying the matrix with the weight of each criterion obtained. After calculating the distance from the matrix of the ideal positive solution, and the negative ideal solution, the relative proximity of each alternative is determined, which represents the performance score of each supplier. Then sort the scores from the largest to the smallest to find out the ranking of the suppliers.

2.4. Multi-objective Optimization (MOO)

Optimization is a widely used technique in operation research to solve many problems. The aim is to maximize or minimize a certain objective function (e.g., maximizing profits or minimizing environmental impact) subject to some constraints. However, in many situations, DMs want to optimize several different objective functions simultaneously. The optimization technique deals with this condition is widely known as Multi-Objective Optimization (MOO). MOO was initially developed from three areas: economic equilibrium and welfare theories, game theory, and pure mathematics (see Marler and Arora [12]). The most robust approach to transform the objective functions, regardless of their original range, is given as follows:

$$F_i^{\text{trans}}(x) = \frac{F_i(x) - F_i^o}{F_i^{\max} - F_i^o} \tag{2.1}$$

This approach is referred to as normalization and will be used in this research. In this case, $F_i^{\text{trans}}(x)$ becomes non-dimensional, which has a value between zero and one, depending on the accuracy and method with which $F_i^{\max}$ and F_i^o are determined.

3. Case Study

This research was conducted in a plastic company that produces plastic mats of various brands and sizes. The company is located in Solo City, the province of Central Java, Indonesia. The company uses Polypropylene (PP) recycled plastic raw materials to reduce production costs. The raw material used by PT WMA has recycled plastic ore made from plastic sacks with different quality grades and supplied from several suppliers. There are eleven kinds of recycled plastic raw materials, and nine alternative suppliers are available in the procurement of raw materials.

In the procurement process, firstly, the company will contact the available suppliers. Then the suppliers will send some samples of plastic ore raw materials and the respective offered price. The delivery of raw materials to the company depends on the agreement between both parties. After the raw material arrives at the company, an inspection will be carried out to check the quality of the plastic ore raw material. The company uses a conventional approach in this case by selecting the supplier based on the lowest price, and the order allocation is based on historical data. Whereas in fact, the low price apparently cannot guarantee the quality of the raw materials.

In this study, the approach is divided into three parts. First, the determination of the weight of each criterion was applied using the BWM method. Second, supplier evaluation and ranking are done using the TOPSIS method, and finally, MOLP is then applied to solve the order allocation problems.

3.1. Implementation of BWM

In this research, BWM is used to obtain criteria weights. Before making a paired comparison vectors, each DM was asked to determine the most important and the worst criteria. DMs were asked to compare their best criteria and formulate their preferences on a scale of 1-9 (the largest the number on the scale, the more important the criteria). For example, DM 1 considered D1 to be the best main criterion, three times as important as D3. The Best-to-Others (BO) vectors are shown in Table 3.

Table 3: BO vectors main criteria.

DM No	Best	D1	D2	D3	D4
1	D1	1	5	3	7
2	D3	3	7	1	4
3	D1	1	3	5	8

Similarly, each DMs were asked to compare the other criteria over the worst criteria. The Others-to-Worst (OW) vectors are shown in Table 4. All criteria and sub-criteria weights are determined by following the same procedures. The average rating of all three DMs on the main criteria is then found by calculating the average value of the weights of each DM. The calculation results are shown in Table 5.

Table 4: OW vectors main criteria.

DM No	1	2	3
Worst	D4	D2	D4
D1	7	5	8
D2	5	1	3
D3	4	7	6
D4	1	3	1

Table 5: Main criteria weights.

Main Criteria	DM No			Average
	1	2	3	
D1	0.561	0.219	0.564	0.448
D2	0.142	0.064	0.241	0.149
D3	0.237	0.553	0.145	0.312
D4	0.059	0.164	0.051	0.091
CR	0.040	0.028	0.036	0.035

Table 6 shows the global criteria weights and their respective rankings. The global sub-criteria weight was calculated by multiplying the main criteria weight with sub-criteria local weights. From the results, we can see that the top five criteria rankings are product price (C1), product quality (C4), on-time delivery (C2), the flexibility of payment (C8), and production capacity (C5). The next step is to select and evaluate supplier alternatives for each raw material using the TOPSIS method.

Table 6: Global criteria weights and the rankings.

Main Criteria	Weight	Sub criteria	Local weight	Global weight	Rank
D1	0.448	C1	1.000	0.448	1
D2	0.149	C2	0.778	0.116	3
		C3	0.222	0.033	7
D3	0.312	C4	0.596	0.186	2
		C5	0.165	0.051	5
		C6	0.104	0.032	8
		C7	0.136	0.042	6
D4	0.091	C8	0.685	0.062	4
		C9	0.098	0.009	10
		C10	0.217	0.020	9

Table 7: Normalized matrix of item 1.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
S1	0.475	0.523	0.439	0.405	0.437	0.456	0.465	0.541	0.510	0.452
S2	0.450	0.432	0.483	0.510	0.500	0.456	0.465	0.456	0.405	0.452
S3	0.533	0.457	0.422	0.510	0.437	0.502	0.533	0.456	0.405	0.517
S4	0.537	0.576	0.630	0.562	0.606	0.575	0.533	0.541	0.642	0.569

3.2. Supplier performance evaluation using TOPSIS method

In this research, TOPSIS calculation was categorized based on the type of raw materials supplied by the suppliers. The results of normalization are shown in Table 7. The weighted normalized decision matrix was obtained by entering the weight of each criterion that has been obtained in the previous calculation using the BWM method in Table 6. The calculation and the results of the weighted normalized decision matrix are shown in Table 8. The last step in TOPSIS is to determine the ideal positive solution and ideal negative solution to find out the value of each supplier's preference for each

Table 8: Weighted normalized matrix of item 1.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
S1	0.213	0.061	0.015	0.075	0.022	0.015	0.020	0.034	0.005	0.009
S2	0.202	0.050	0.016	0.095	0.026	0.015	0.020	0.028	0.004	0.009
S3	0.239	0.053	0.014	0.095	0.022	0.016	0.023	0.028	0.004	0.010
S4	0.240	0.067	0.021	0.104	0.031	0.019	0.023	0.034	0.006	0.011

type of raw materials. Table 9 shows TOPSIS calculation results and ranking of each supplier for each raw material.

Table 9: TOPSIS calculation ranking each item.

Supplier	Item										
	1	2	3	4	5	6	7	8	9	10	11
1	3	1	3	1		2	2	2			2
2	1				3		3		3	3	
3	4	3	5	3	4	3		1		5	
4	2	2	4		2	1					
5			1		5		4		2	4	
6			2	2							1
7					1		1		1		
8										1	
9										2	

3.3. Implementation of MOLP

The objective functions used in the MOLP model are: minimizing the cost of raw materials (Eq. (1)) and maximizing the organizational utility using the results obtained from MCDM (Eq. (2)).

3.3.1. Notation and parameters

Indices

i = Index of raw material i, $i = 1, 2, \ldots, I$,

j = Supplier j, $j = 1, 2, \ldots, J$.

Decision variables

Q_{ij} = Amount of raw materials i ordered to suppliers j,

$$X_j \quad \begin{cases} 1, & \text{if supplier } j \text{ is selected for raw material,} \\ 0, & \text{otherwise.} \end{cases}$$

Parameters

P_{ij} = The price of raw material i offered by supplier j,

S_{ij} = Supplier scores for raw materials i from suppliers j obtained by TOPSIS,

D_i = Demand of raw material i,

Cap_{ij} = Maximum capacity for raw materials i from suppliers j,

M = A positive big number.

3.3.2. The order allocation

The formulation of order allocation model is as follow:

$$\min Z_1 = \sum_i \sum_j Q_{ij} \times P_{ij}, \tag{3.1}$$

$$\min Z_2 = \sum_i \sum_j S_{ij} \times Q_{ij}, \tag{3.2}$$

Subject to:

$$\sum_j Q_{ij} = D_i, \tag{3.3}$$

$$Q_{ij} \leq Cap_{ij}, \tag{3.4}$$

$$\sum_i Q_{ij} \leq M \times X_j, \tag{3.5}$$

$$Q_{ij} \geq 0 \text{ \& integere}, \tag{3.6}$$

$$X_j \in \{0, 1\} \tag{3.7}$$

Equation (2) describes the first objective function and aim to minimize the total cost of raw materials. The second objective function in Equation (3) attempt to maximize the score of suppliers. Constraint (4) ensures that the number of items i ordered from supplier j is equal with the total demand of item i. Constraint (5) ensures that the amount of item i ordered from supplier j is equal to or less than each supplier's capacity for each item. Constraint (6) ensures that if the decision is to purchase an item i from supplier j, firstly the supplier should be selected. Constraint (7) deals with nonnegativity integer variables, while Constraint (8) defines the binary variable.

Table 10 shows the input data collected from the company. These data comes from nine suppliers for eleven items. The resulted optimal allocation of raw materials to each supplier is shown in Table 11.

3.4. Sensitivity analysis

For the sensitivity analysis, several scenarios are developed. The scenario of changing demand parameters is carried out based on the distribution of data on raw material needs every month, where the percentage change in scenario values is 20%, 40%, 60%, and 80%. This value is used to both increases and decrease the need for raw materials.

In the sensitivity analysis, we assume that the production capacity of each supplier is able to meet the demand in each month for each raw material. So that if there are suppliers who have low capacity, it is assumed that these suppliers can increase their capacity. Supplier capacity is assumed to increase by 20% when demand increases from 20% to 80%. If there are several suppliers who are still unable to meet the needs of certain raw materials, a capacity increase of a multiple starting from 5% of the initial supplier capacity is applied. The results of sensitivity analysis are shown in Table 12.

Figure 1 shows the effect of demand change to the objective functions. From the figure, we can see that the company can reach the optimal point in minimizing costs

Table 10: Input data.

Item	Demand	Supplier	Price	Capacity	Item	Demand	Supplier	Price	Capacity
1	5700	1	9299	2000	6	11100	1	8750	1200
		2	8800	1000			3	10420	1200
		3	10420	900			4	9910	10500
		4	10497	4700	7	9850	1	8425	1600
2	3800	1	8270	2500			2	9133	1700
		3	9925	800			5	9542	7700
		4	9656	2500			7	8700	1600
3	11500	1	9800	800	8	2000	5	9622	3500
		3	12620	1800			7	8700	1400
		4	11700	1900	9	8600	2	9133	1600
		5	10064	2900			5	9533	7500
		6	10575	6700			7	8700	1600
4	3850	1	8956	1000	10	16500	2	10263	3700
		3	9875	900			3	10600	760
		6	10633	4200			5	9500	3200
5	5600	2	9400	1200			8	9794	4000
		3	10300	750			9	10493	8300
		4	10400	740	11	3000	1	9650	800
		5	9800	850			6	10690	3600
		7	10150	5300					

Table 11: The order allocation of raw material.

Supplier	Order Allocation per Item (kg/month)										
	1	2	3	4	5	6	7	8	9	10	11
1	2000	2500	800	1000		1200	1600	600			800
2	1000				300		1700		1600	3700	
3	0	0	0	900	0	0		1400		0	
4	2700	1300	1100		0	9900					
5			2900		0		4950		5400	3200	
6			6700	1950							2200
7					5300		1600		1600		
8										4000	
9										5600	

when demand reaches 80%. This means the company must increase its production capacity which means the increase of raw material requirements by up to 80%. Hence, the company must increase the sales target of plastic mats by expanding its market. If the

Table 12: The results of sensitivity analysis.

Scenario	Q_{ij}											
	Item 1				Item 2			Item 3				
	Q_{11}	Q_{12}	Q_{13}	Q_{14}	Q_{21}	Q_{23}	Q_{24}	Q_{31}	Q_{33}	Q_{34}	Q_{35}	Q_{36}
80%	2400	1200	1020	5640	3000	840	3000	1200	2250	2850	4350	10050
60%	2400	1200	0	5520	3000	80	3000	1080	1795	2565	3915	9045
40%	2400	1200	0	4380	3000	0	2320	960	1340	2280	3480	8040
20%	2400	1200	0	3240	3000	0	1560	960	0	1320	3480	8040
Base Case	2000	1000	0	2700	2500	0	1300	800	0	1100	2900	6700
-20%	2000	1000	0	1560	2500	0	540	800	0	0	2900	5500
-40%	2000	1000	0	420	2280	0	0	800	0	0	2900	3200
-60%	1280	1000	0	0	1520	0	0	800	0	0	2900	900
-80%	140	1000	0	0	760	0	0	0	0	0	2300	0

Scenario	Item 4			Item 5					Item 6		
	Q_{41}	Q_{43}	Q_{46}	Q_{52}	Q_{53}	Q_{54}	Q_{55}	Q_{57}	Q_{61}	Q_{63}	Q_{64}
80%	1200	1080	4650	1440	372	888	1020	6360	1860	1845	16275
60%	1200	1080	3880	1440	0	888	272	6360	1680	1380	14700
40%	1200	1080	3110	1440	0	40	0	6360	1512	798	13230
20%	1200	1080	2340	360	0	0	0	6360	1440	0	11880
Base Case	1000	900	1950	300	0	0	0	5300	1200	0	9900
-20%	1000	900	1180	0	0	0	0	4480	0	0	8880
-40%	1000	900	410	0	0	0	0	3360	0	0	6660
-60%	1000	540	0	0	0	0	0	2240	0	0	4440
-80%	770	0	0	0	0	0	0	1120	1200	0	1020

Scenario	Item 7				Item 8		Item 9		
	Q_{71}	Q_{72}	Q_{75}	Q_{77}	Q_{85}	Q_{87}	Q_{92}	Q_{95}	Q_{97}
80%	2320	2465	10625	2320	1920	1680	2320	10840	2320
60%	2080	2210	9390	2080	1520	1680	2080	9600	2080
40%	1920	2040	7910	1920	1120	1680	1920	8200	1920
20%	1920	2040	5940	1920	720	1680	1920	6480	1920
Base Case	1600	1700	4950	1600	600	1400	1600	5400	1600
-20%	1600	1700	2980	1600	200	1400	1600	3680	1600
-40%	1600	1700	1010	1600	0	1200	1600	1960	1600
-60%	1600	740	0	1600	0	800	1600	240	1600
-80%	370	0	0	1600	0	400	120	0	1600

Scenario	Item 10					Item 11	
	Q_{102}	Q_{103}	Q_{105}	Q_{108}	Q_{109}	Q_{111}	Q_{116}
80%	5550	900	4800	6000	12450	1040	4360
60%	4995	480	4320	5400	11205	960	3840
40%	4440	60	3840	4800	9960	960	3240
20%	4440	0	3840	4800	6720	960	2640
Base Case	3700	0	3200	4000	5600	800	2200
-20%	3700	0	3200	4000	2300	800	1600
-40%	2700	0	3200	4000	0	800	1000
-60%	0	0	2600	4000	0	800	400
-80%	0	0	0	3300	0	600	0

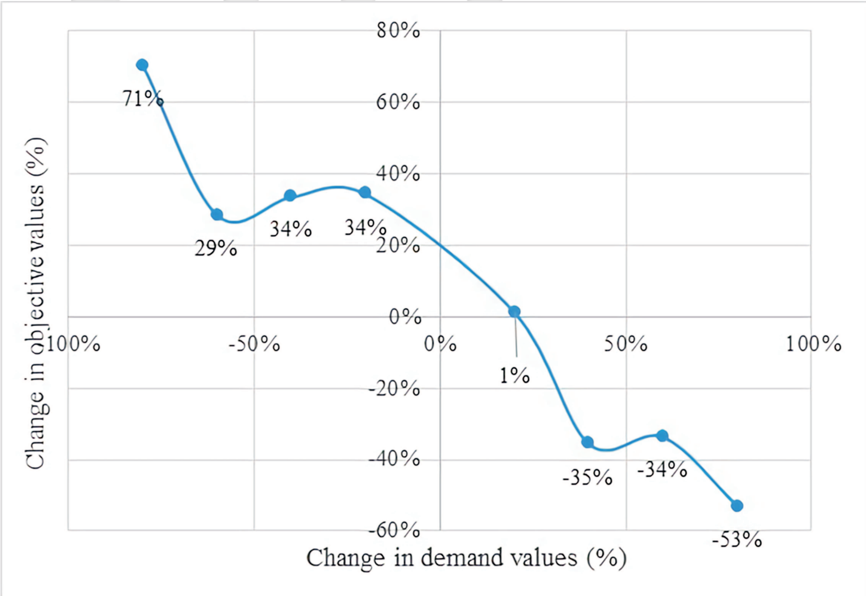

Figure 1: Results of sensitivity analysis of the changing demand parameter for objective values.

sales are increased, then the production will also increase and eventually increasing the raw material requirements.

Based on the results of the sensitivity analysis, the demand parameter (D) is sensitive to the decision variable (Q_{ij}) on each item of raw material and the value of the objective function. Thus, both companies and suppliers must pay more attention to the demand parameters or the needs of plastic ore raw materials every month, because a slight change in these parameters can have a major influence on the decision variables and objective functions.

The demand parameter is directly proportional to each decision variable because if there is an increase in raw material requirements, the number of raw materials ordered by suppliers will also increase, and vice versa. Another parameter that needs to consider is supplier capacity because of the limited capacity of the suppliers so that the company cannot overcome the problem if there is an increase in demand. Therefore, a step that might be used by companies is to find new suppliers that can meet the shortage of raw material requirements. However, this might be difficult to be implemented since each supplier specializes in supplying only certain raw materials. So, the other alternative is by increasing the supplier's capacity. In this sensitivity analysis, supplier capacity parameters are assumed to meet all raw material requirements. Hence, in the real system, the company has to pay more attention to supplier capacity in the demand uncertainty situation of plastic ore raw material. Based on the results of BWM as shown in Table 6, there are three dominant sub criteria: price, quality, and on time delivery. Hence, the decreased quality of a supplier will make the supplier lost an opportunity to be selected.

4. Conclusion

In this research, BWM and TOPSIS methods were used to solve the supplier selection problem. Ten criteria were used in this research to evaluate the suppliers. The BWM method was used to determine the weight of each criterion, while TOPSIS was used to rank each supplier. The results of both methods were then used as inputs for the MOLP model to determine the optimal order allocation of raw materials to each supplier. The results of the sensitivity analysis showed that the change in demand would have significant effects on the decision variables and objective functions.

The company needs to pay more attention to supplier capacity to anticipate the increase in plastic ore raw material requirements. The methods used in this study can be applied to other companies that have the same problems with the company under study. In further research, the order allocations can be extended to include inventory decision problems.

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