Supplier selection of recycled plastic materials using best worst and TOPSIS method

Rahma Sulistyoningarum, Cucuk Nur Rosyidi, Taufiq Rochman

1Industrial Engineering Department, Universitas Sebelas Maret, Jawa Tengah, Indonesia
2Production System Laboratory, Industrial Engineering Department, Universitas Sebelas Maret, Jawa Tengah, Indonesia
3Product Planning and Design Laboratory, Industrial Engineering Department, Universitas Sebelas Maret, Jawa Tengah, Indonesia

E-mail: rahmaarum97@gmail.com

Abstract. Supplier selection problem is one of the most important business activities related to sustainable development because it has significant effect on product quality and quantity and sustainability issues. PT Wonorejo Makmur Abadi is a plastic manufacturing company that produces plastic mats in many various brands and sizes. The raw materials used are recycled Polypropylene (PP) type of plastic raw materials to reduce mat production costs. There are several criteria that must be considered in determining suppliers including price, delivery, capability, and flexibility. The company must be careful in making decisions in supplier selection because there are several criteria that must be considered simultaneously. Therefore, in this paper, a decision-making tool is provided to solve the sustainable supplier selection in multi-item and multi-supplier environment. At first, one of the efficient Multiple Criteria Decision Making (MCDM) approaches called Best Worst Method (BWM) is used to determine the weight of each criterion, where the weight will be used in the evaluation of each supplier to select the most appropriate supplier using the Technique For Reference Orders By Similarity To Ideal Solution (TOPSIS) method. The results of this research can help managers in this plastic industry to deal with the sustainable supplier selection problem. Furthermore, the presented approach in this research can assist managers of other industries to select and evaluate their suppliers.

1. Introduction

In today’s competitive industrial era, a company must cooperate with suppliers to ensure the availability of raw materials. Some companies are faced with problems in choosing one or more from a set of suppliers. Therefore, the selection of suppliers is included in the issue of multi-criteria decision making (MCDM) where companies need to identify the priorities in supplier selection based on performance and type of industry [1]. 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. Choosing the right supplier not only including the material cost, but also other quantitative and qualitative criteria [2]. Selection of suppliers is one of the most important decision-making problem 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 [3]. Selection of suppliers is one of the most important business activities that has a significant effect on product quality [4].

PT Wonorejo Makmur Abadi (WMA) is a plastic company that produces plastic mats of various brands and sizes. PT WMA uses Polypropylene (PP) recycled plastic raw materials to reduce the production costs. The raw material used by PT WMA is recycled plastic ore from plastic sacks that have high quality and lower quality materials. The raw materials are supplied from several suppliers. There are eleven kinds of recycled plastic raw materials and nine alternative suppliers that cooperate with the company in the procurement of raw materials.

Firstly, the company will contact the suppliers for raw materials procurement. Then the suppliers will send some samples of plastic ore raw materials and the respective offered price. PT WMA will choose suppliers with the lowest price in the procurement. The low price apparently cannot guarantee the quality of the raw materials. In addition there are other criteria that must be considered simultaneously in determining suppliers, including price, shipping, capability, and supplier flexibility. In practice, decision making is done intuitively with no clear weight among criteria. Decision making with this method cannot guarantee the consistency in the assessment of prospective suppliers.

This research is conducted to evaluate and select the appropriate supplier for PT WMA. Supplier selection is done by considering several criteria. It is expected that the selection of the right supplier can reduce costs and increase the competitiveness of the company. The selection of suppliers of raw materials are calculated using a combination of the best-worst method (BWM) and a technique for reference orders by similarity to ideal solution (TOPSIS). The BWM method is used to determine the weight of each criterion, where the weight will be used in the evaluation of each supplier using the TOPSIS method. PT WMA is expected to be able to select and evaluate suppliers so that the company can determine the suitable criteria and alternative suppliers.

2. Literature review

In this current industrial era, evaluation and selection of suppliers in many industries and business are considered as an important activity [5]. The research aims to determine raw material suppliers for an electronics manufacturing company in Taiwan. To solve this problem, he proposed to use integration between BWM, fuzzy TOPSIS and FMOLP, in which qualitative and quantitative factors were involved. The BWM method was used to obtain criteria weights and modified fuzzy TOPSIS to evaluate supplier rankings. While the FMOLP model is used to determine order allocations for each qualified supplier. [6] proposed a multi-criteria model in the supplier selection process when outsourcing activities in the textile industry in Brazil. They performed three steps in this research; Copeland method used to aggregate criteria in supplier selection, AHP method used to determine criteria weights for those criteria, and ELECTRE-TRI method used to classify the suppliers performed.

Supplier selection is the key and substantial process in the company's purchasing strategy, which then becomes one of the important factors to achieve the company's targets. [7] 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. [8] conducted 3 steps decision making procedure. The first step included the selection of criteria through study literature and interviewed with the company manager. Next, determined the criteria weights using BWM. The last step was selecting and ranking the alternative suppliers for each item based on criteria weights. [9] used a new MCDM method called BWM to obtain criteria weights which used in a high-tech Chinese company that specialized in testing instruments. All of 87 suppliers considered were evaluated to their capabilities and willingness criteria. Each supplier was evaluated in regard to seven willingness criteria and eleven capabilities criteria. BWM has several important features that make it a robust and user-friendly method compared to most MCDM methods. The method requires less data in more reliable results, and also it does not use fractional numbers so it is easier to understand by the DM [9].

[3] recommended a system using the TOPSIS method that can help purchasing managers to evaluate the best suppliers in the form of priority of the three alternatives of egg suppliers and five
criteria. The rank order centroid (ROC) method was chosen to determine the weights of criteria in order to lessen the degree of subjectivity from the decision makers as well as uncertainty of the weights assignment. The criteria used were product quality, packaging quality, product price, delivery performance, and serviceability. [4] developed two main objectives, which were choosing the right supplier and calculating optimal allocation order based on several criteria used in supplier assessment. The criteria included cost, quality, delivery, loyalty, technology, financial situation, service. The BWM method was used to determine the weight of each criterion and preference of potential suppliers according to these criteria. Then the MILP model was used to minimize costs and maximize the total performance score of all suppliers. Among all the articles in the supplier selection problem that have been described, several studies considered the criteria of price, delivery, quality, and flexibility in their supplier selection issues. According to the characteristics described, we believe that this research has a significant contribution. In summary, the research contributions can be seen in Table 1.

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

| Reference | Criteria | Model Specification | Solution approach |
|-----------|----------|---------------------|-------------------|
| [9]       | * * *    | MI                  | BWM               |
| [10]      | * *      |                     |                   |
| [8]       | * * *    | MI                  | BWM-Fuzzy TOPSIS  |
| [3]       | * * *    | SI                  | TOPSIS            |
| [4]       | * * *    | * MI                | BWM-RMCGP         |
| [11]      | * * *    | * MI                | BWM, fuzzy TOPSIS, and FMOLP |
| [6]       | * * *    | * SI                | AHP-ELECTRE       |
| [7]       | * * *    | MI                  | Fuzzy TOPSIS      |
| This research | * * *    | MI                  | BWM-TOPSIS       |

Notes: *S/M-I: Single/Multi-Item *OA: Order allocation

3. Methodology

3.1. Supplier selection criteria
In this research, supplier selection criteria were collected from previous studies, mainly the ones in Table 1. Afterwards, the criteria were assessed by each Decision Maker (DM) that has been selected based on the results of company meetings. Each DM comes from various departments, such as procurement department, warehouse section, and production department. The selected criteria for this research are shown in Table 2.

3.2. Best worst method (BWM)
BWM method was first introduced by [12] to solve multi criteria problem decision-making. In the MCDM problem, several alternatives will be evaluated with related criteria to choose the best ones. Based on the BWM method, the choice of the best criteria (eg 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 decision maker. Furthermore, comparison of the pairing is done between the best criteria and the worst criteria along with other criteria.

| Table 2. Selected criteria and sub-criteria |
|-------------------------------------------|
| **Criteria** | **Price (D1)** | **Delivery (D2)** | **Capability (D3)** | **Flexibility (D4)** |
| Product price (C1) | On time delivery (C2) | Product quality (C4) | Payment flexibility (C8) |
| Accuracy of the order sent (C3) | Production capacity (C5) | Flexibility of changing orders (C9) |
| Supplier reliability (C6) | Flexibility of delivery time (C10) |
| Information of price changes (C7) |

[12] also 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 comparison in BWM method is always reliable, while other MCDM methods such as AHP method, the result is not always reliable. BWM is a vector-based method that needs fewer comparisons compared to matrix-based MCDM such as AHP. While using comparison matrix, AHP has to deal with fractional numbers, however BWM used only integer number that make it much easier to use. For more details about BWM method including its steps please refer to the research by [12].

3.3. Technique For Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is one of the multicriteria decision-making methods. TOPSIS 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 using Euclidean distance 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 TOPSIS method is easier to understand and simpler to implement compared with other outranking methods such as PROMETHEE and ELECTRE [12].

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

4. Case Study

This study aims to solve sustainable supplier selection problems involving uncertain or unavailable information. To achieve this goal, we use a combination of BWM and TOPSIS method to conduct selection and evaluation of nine alternative suppliers in eleven types of plastic ore raw materials at PT WMA. Before collecting the data for prospective suppliers, a list of the 4 main criteria and 10 sub criteria based as shown in Table 2 presented to the DMs and they were asked to choose only the ones that will be used to select the suppliers.

4.1. Implementation of BWM

This research used BWM to obtain criteria weights. Before making a paired comparison vectors, each DM is asked to determine the most important and the worst criteria. DMs were asked to compare their
best criteria and formulate their preferences on 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. 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. The weight of each criterion can be determined by each DM based on BO and OW vectors. All criteria and sub criteria weights are determined by following the same procedures.

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  |

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 shows the average rating of all three DMs on the main criteria.

Table 5. Main criteria weights

| Main Criteria | DM No 1 | DM No 2 | DM No 3 | Average |
|---------------|---------|---------|---------|---------|
| 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 as their respective rankings. The global sub-criteria weight was calculated by multiplying the main criteria weight by sub-criteria local weights.

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         |      |
| 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    |
From the results, we can see that the top five criteria rankings were product price (C1), product quality (C4), on time delivery (C2), payment flexibility (C8), and production capacity (C5). The next step is to select and evaluate supplier alternatives for each raw material using the TOPSIS method.

4.2. Supplier performance evaluation using TOPSIS method

In this study, the TOPSIS calculation was categorized based on the type of raw materials supplied by the suppliers. The calculation was done and shown in Table 7.

| Supplier | Item 1 | Item 2 | Item 3 | Item 4 | Item 5 | Item 6 | Item 7 | Item 8 | Item 9 | Item 10 | Item 11 |
|----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|---------|
| S1       | 3      | 1      | 3      | 1      | 2      | 2      | 2      | 2      | 2      | 2       |         |
| S2       | 2      | 2      | 4      | 2      | 1      |        |        |        |        |         |         |
| S3       | 4      | 3      | 5      | 3      | 4      | 3      | 1      | 5      |        |         |         |
| S4       | 2      | 2      | 4      | 2      | 1      |        |        |        |        |         |         |
| S5       | 1      | 5      | 4      | 2      | 4      |        |        |        |        |         |         |
| S6       | 2      | 2      | 1      | 2      | 1      |        |        |        |        |         |         |
| S7       | 1      | 1      | 1      | 1      | 1      |        |        |        |        |         |         |
| S8       |        |        |        |        |        |        |        |        | 1      |         |         |
| S9       |        |        |        |        |        |        |        |        | 2      |         |         |

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 into the decision matrix. The calculation was done and the results of weighted normalized decision matrix shown in Table 8. The last step is to determine the ideal positive solution and negative ideal solution so that it can be seen the distance of each supplier to the positive ideal point and negative ideal point which used to find out the value of each supplier's preference for each type of raw materials. Table 9 shows TOPSIS calculation results and ranking of each supplier for each raw material.

| Supplier | Item 1 | Item 2 | Item 3 | Item 4 | Item 5 | Item 6 | Item 7 | Item 8 | Item 9 | Item 10 | Item 11 |
|----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|---------|
| S1       | 3      | 1      | 3      | 1      | 2      | 2      | 2      | 2      | 2      | 2       |         |
| S2       | 1      | 3      | 3      | 1      | 2      | 2      | 2      | 2      | 2      | 2       |         |
| S3       | 4      | 3      | 5      | 3      | 4      | 3      | 1      | 5      |        |         |         |
| S4       | 2      | 2      | 4      | 2      | 1      |        |        |        |        |         |         |
| S5       | 1      | 5      | 4      | 2      | 4      |        |        |        |        |         |         |
| S6       | 2      | 2      | 1      | 2      | 1      |        |        |        |        |         |         |
| S7       | 1      | 1      | 1      | 1      | 1      |        |        |        |        |         |         |
| S8       |        |        |        |        |        |        |        |        | 1      |         |         |
| S9       |        |        |        |        |        |        |        |        | 2      |         |         |

5. Conclusion

In this research, BWM and TOPSIS method are used to solve the supplier selection problem. There are ten criteria used by PT. Wonorejo Makmur Abadi in determining and evaluating suppliers. Here, all ten criteria are considered based on the results of interviews with experts and literature studies that have been conducted. Then BWM method is used to determine the weight of each criterion. One of the main features of this method is having less comparison and more reliable results compared to other techniques such as AHP. The criteria with the respective weight using BWM method are product price (0.448), on time delivery (0.116), accuracy of the order sent (0.033), product quality (0.186),
production capacity (0.051), supplier reliability (0.032), information of price changes (0.042), payment flexibility (0.062), flexibility of changing orders (0.009), flexibility of delivery time (0.020). The evaluation of suppliers with the TOPSIS method obtained the best supplier in each eleven raw materials. From the result, we can see that supplier 1 is the best supplier for item 2 and item 4, supplier 2 is the best supplier for item 1. Supplier 3 is the best supplier for item 8, supplier 4 is the best supplier for item 6, supplier 5 is the best supplier for item 3, supplier 6 is the best supplier for item 11, supplier 7 is the best supplier for item 5, item 7, and item 9. Supplier 8 is the best supplier for item 10. The contribution of research with the BWM and TOPSIS methods can help PT Wonorejo Makmur Abadi in selecting and evaluating plastic ore raw materials suppliers according to the main criteria in addition to other criteria that can be considered in determining suppliers. Further research is recommended to determine the allocation of raw material orders to help companies obtain the allocation of each selected supplier for each raw material. Then, the final results of TOPSIS calculation will be used as input in the utility maximization objective function of the linear programming model. The criteria used in supplier selection problem will be vary according to the actual conditions and problems in the company under study, so the results of supplier evaluations can also be different. The BWM and TOPSIS methods as used in this study, can be applied to other companies that have the same problems with the company in this research.

References
[1] Cebiy F and Bayraktar D 2003 An integrated approach for supplier selection. Journal of logistics information management
[2] A E Cengiza, O Aytek i , I Ozdemirb, H Kusanb, A Cabukab 2017 A Multi-Criteria Decision Model for Construction Material Supplier Selection. 294 – 301
[3] Sureeyatanapas P, Sriwattananusart K, Niyamosothath T, Set W, and Arun S 2017 Supplier selection towards uncertain and unavailable information: an extension of TOPSIS method. Operations Research Perspectives
[4] Cheraghalipour and Farsad 2018 A bi-objective sustainable supplier selection and order allocation considering quantity discounts under disruption risks: A case study in plastic industry. Computers & Industrial Engineering
[5] Junior Fransisco R L, Osiro L, and Carpinetti Luiz C R 2014 A comparison between Fuzzy AHP and Fuzzy TOPSIS methods to supplier selection. Applied Soft Computing. 21 194–209
[6] Guarnieri P and Trojan F 2019 Decision making on supplier selected based on social, ethical, and environmental criteria: A study in the textile industry. Resources, Conversation and Recycling. 141 347-361
[7] Memari A, Dargi A, Jokar Mohammed R A , Ahmad R , and Rahim A, Rahman Abd 2019 Sustainable supplier selection: A multi-criteria intuitionistic fuzzy TOPSIS method. Journal of Manufacturing System. 50 9-24
[8] Gupta H and Barua MK 2017 Supplier selection among SMEs on the basis of their green innovation ability using BWM and fuzzy TOPSIS. Journal of Cleaner Production. 152 242-58
[9] Rezaei J, Wang J, and Tavasszy L 2015 Linking supplier development to supplier segmentation using Best Worst Method. Expert Systems with Applications. 42 9152-9164
[10] Zimmer Konrad, Frohling M, and Schultmann F 2015 Sustainable supplier management – a review of models supporting sustainable supplier selection, monitoring and development. International Journal of Production Research
[11] Lo H W, Liou James J H, Wang H S, and Tsai Y S 2018 An integrated model for solving problems in green supplier selection and order allocation. Journal of Cleaner Production. 190 339-352
[12] Rezaei J 2015 Best-worst multi-criteria decision-making method. Omega. 53 49–57
[13] Taherdoost, Hamed and Brard Aurelie 2019 Analyzing the process of supplier selection criteria and methods. Procedia Manufacturing. 32 1024-1034