Risk analysis for sustainable supplier selection

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Abstract. One of the important factors to survive in a competitive market is sustainable supplier selection. It is especially important because suppliers, who consider three dimensions of sustainability, namely economic, social, and environmental, are upstream players in the supply chain. Considering risk to choose the best supplier may lead to a more extensive and complex sustainable supplier selection process. Therefore, not only will the supplier selected by its performance but also by considering the unexpected deviations. In particular, to tackle this issue, this paper proposes a sustainable supplier selection model by integrating the DEMATEL-ANP and FMEA methods by considering supplier risk in the decision process. The result shows that the best supplier which aligns with the criteria for selecting sustainable suppliers. Moreover, it has a smaller risk compared to other suppliers. As a representative in this research is a pharmaceutical company.

Keywords: Sustainable supplier selection, DEMATEL, ANP, FMEA

1. Introduction

The need for health services in Indonesia is increasing every year and the role of the pharmaceutical industry is needed in managing the availability of medicines and medical devices. In fulfilling drug raw materials, it still has limitations because pharmaceutical companies have a dependency on imported raw materials of about 95%. In the global supplier, there are several risks that occur, one of which is the supplier of Apple company in China that violates security and the environment. The supplier conducts air pollution such as emissions of poisonous gas and the disposal of heavy metal waste which causes illness for the people who live around the supplier's factory. The case resulted in several organizations and communities in China boycotting all Apple products and harming Apple's company. The events that have occurred above directly affect the sustainability of the supply system of raw materials in the company. If the disruption continues and requires a long recovery time, the company's business processes can be disrupted and cause the company can not meet market demand.

To reduce the risks that occur in the material supply chain flow, it is necessary to have an appropriate supplier selection and assessment system[1].

In producing products, companies not only pay attention to economic and social aspects but also can consider environmental aspects, so that companies can contribute to achieving sustainable development. In addition to the government's demand for the company's contribution in realizing sustainable development, it turns out there are consumer demands on the company to produce sustainable products. According to [2] the company is not only responsible for using the concept of sustainability in its production process, but also must consider the concept of sustainability in selecting
suppliers. Selection of sustainable suppliers is a very important activity in the supply chain, because suppliers are the upstream of the supply chain. To evaluate suppliers in the process of selecting sustainable suppliers, a decision analysis is needed to determine which criteria are most influential in selecting suppliers. These criteria will support the supplier evaluation process and determine the suppliers to be selected. The supplier evaluation process is carried out in order to compare several suppliers who will then make a decision on which suppliers to choose. In the decision making process in determining the best suppliers from several suppliers, a multi-criteria decision making (MCDM) method is used because this method in making decisions involves more than one criterion. These criteria will support the supplier evaluation process and determine the suppliers to be selected. The supplier evaluation process is carried out in order to compare several suppliers who will then make a decision on which suppliers to choose. In the decision making process in determining the best suppliers from several suppliers, a multi-criteria decision making (MCDM) method is used because this method in making decisions involves more than one criterion. These criteria will support the supplier evaluation process and determine the suppliers to be selected. The supplier evaluation process is carried out in order to compare several suppliers who will then make a decision on which suppliers to choose. In the decision making process in determining the best suppliers from several suppliers, a multi-criteria decision making (MCDM) method is used because this method in making decisions involves more than one criterion.

Based on research that has been done previously regarding the selection of sustainable suppliers [3] - [6] that very few consider the interrelationship between criteria in the selection of sustainable suppliers and in some cases that occur there are decision-making problems that are not structured hierarchically because there are interactions and dependencies between criteria. In addition, the process of selecting sustainable suppliers by considering the risk of making considerations in the selection of suppliers will be more extensive and complex so that the selected suppliers are not only seen based on performance, but also considered unexpected deviations from suppliers. Therefore, this study aims to create a sustainable supplier selection model by considering supplier risk by integrating the DEMATEL-ANP and FMEA methods.

2. The Material and Method

2.1 Decision-Making Trial and Evaluation Laboratory (DEMATEL)

DEMATEL is a method for building and analyzing structured models and there is a causal relationship between the factors [7]. There are several completion steps in the DEMATEL method as follows:

- Make a direct relationship matrix.
  Assessment of the relationship between these criteria in the form of matrix A pairwise comparison with the number of nxn for each expert where $a_{ij}$ is the level of influence of factor i on factor j whose judgment is carried out by expert to k.

- Normalization of the direct relationship matrix
  Based on the matrix A relationship, then normalizing the direct X matrix relationship using the following equation:

  \[
  X = k \cdot A
  \]

  \[
  k = \frac{1}{\max_{i=1}^{n} \sum_{j=1}^{n} a_{ij}}
  \]

  where $i, j = 1, 2, ..., n$

- Get a total relationship matrix
  The total relationship matrix or the T matrix symbolized as the identity matrix is obtained using the following equation:

  \[
  T = X (1 - X)^{-1}
  \]

- Calculating vector dispatch (D) and receiver (R)
Each dispatcher vector (D) and receiver (R) will correspond to the number of rows and columns in the T matrix. The D + R value indicates the importance of a criterion with other criteria. The greater the value, the higher the relevance. If the D-R value is positive, it indicates that a criterion is a cause and an impact to other criteria. Whereas if the D-R value is negative, it indicates that a criterion is receiving an impact from other criteria. Calculation of D and R using the following equation:

\[ T = [t_{ij}]_{nxn} \quad i, j = 1,2,3, \ldots, n \]  

(3)

\[ D = \left[ \sum_{j=1}^{n} t_{ij} \right]_{nx1} = [t_{f}]_{nx1} \]  

(4)

\[ R = \left[ \sum_{j=1}^{n} t_{ij} \right]_{1xm} = [t_{f}]_{nx1} \]  

(5)

- Make a causal diagram

Based on the results of the total matrix T which provides information about the relationship between criteria (as much as the effect of criterion i on criterion j) then all of that information will be converted in a causal diagram.

2.2 Analytic Network Process (ANP)

ANP is one method that can be used to solve MCDM problems. The ANP method is a method of developing the Analytic Hierarchy Process (AHP) method, where the ANP method is able to make decisions involving interactions and interrelationships between criteria and reciprocity of criteria in clusters and between clusters [8]. Some stages in decision making with the ANP method are as follows:

- Structure the problem and develop a linkage model
  Determine the goals or objectives of problem solving, determine criteria referring to control criteria, and determine alternative choices.

- Form a comparison matrix and comparison scale
  The decision maker will make a pairwise comparison of all elements in the ANP structure using a scale of 1-9 where 1 (equally important) to 9 (absolutely more important). Eigenvector comparison matrix with the following equation:

\[ A \cdot w = \lambda_{max} \cdot w \]  

(6)

Where A is a pairwise comparison matrix, w is the eigenvector and is the largest eigenvalue, \( \lambda \)

- calculate the consistency rating of an expert

\[ CI = (\lambda_{max} - n) / (n-1) \]  

(7)

To calculate the consistency ratio obtained from the comparison of the consistency index and the number of random consistency index (RI).

\[ CR = \frac{CI}{RI} \]  

(8)

- Make Supermatrix

Supermatrix is the result of priority vectors from pairwise comparisons between clusters, nodes, and alternatives. Supermatrix consists of 3 stages namely, unweighted supermatrix (unweighted supermatrix), weighted supermatrix (weighted supermatrix) and supermatrix limit (limiting supermatrix).

2.3 Failure Mode and Effects Analysis (FMEA)

The FMEA method used in this study adopts the research that has been done [9] where there is an improvement in the calculation of the Risk Priority Number (RPN). Failure mode is an unexpected deviation from supplier performance where failure mode will be in accordance with supplier selection criteria. FMEA was developed for supplier selection by giving a "discount" on the criteria weights.
According to the risk of each supplier. So that suppliers who have high risk, will get a big "discount" on the criteria weights. The weighted criteria that have been given a "discount" will be the final weight for analysis of supplier selection. Equations (9) through (11) are used for FMEA calculations while equation (11) is an integration formulation for DEMATEL-ANP and FMEA.

\[ R = S \times O \]  
(9)
\[ ep = -0.1 \times D + 1.55 \]  
(10)
\[ RPN = \left( \frac{R-1}{99} \right)^{ep} \times 100 \]  
(11)

\[ Risk \ discount = Bot\ Bot\ Kriteria\ dari\ DEMATEL\ ANP \times \left( 1 - Risk \right) \]  
(12)

2.4 Case Study

PT. ABC is one of the largest pharmaceutical companies in Indonesia. This company produces and markets medicines in Indonesia. Until now, PT. ABC has produced more than 284 kinds of products and is grouped into products with trade names, generic drug products, government ordered products and patent products. In addition the company also manufactures licensed products from companies in several countries. In addition to meeting national needs, PT. ABC carried out drug export cooperation to several countries that have been pioneered since 2013. Before identifying the supplier selection criteria, the determination of raw materials and their suppliers is the first object of observation in this study. At this stage observations and interviews were carried out at the procurement department to obtain appropriate raw materials and suppliers for this research. PT. ABC produces several medicinal products, but the main product produced is medicine A. Active Raw Materials used in making medicine A are active raw materials X. To meet this demand there are several active raw material suppliers X namely supplier 1, supplier 2 and suppliers 3. Some of these suppliers will be alternatives in the ANP network model.

The criteria and sub-criteria were adopted from several previous studies, then submitted and conducted interviews with the procurement department expert PT XYZ. The aim is to determine which criteria and sub-criteria are consistent with the strategy of PT. XYZ Table 1 shows a list of criteria and sub-criteria that suppliers have verified.

| Criteria                                | Sub-criteria                                                                 |
|-----------------------------------------|-----------------------------------------------------------------------------|
| 1 Cost / Price                          | Product price, Transportation cost, Payme nt term, Duty                     |
| 2 Delivery                              | On time delivery, Lead Time                                                 |
| 3 Quality                               | Supplier certification, Chemical purity                                     |
| 4 Production Facilities and Capacity    | Supply capacity, Size of product                                            |
| 5 Service                               | After sales service, Warranty                                               |
| 6 Pollution production                  | Financial stability                                                        |
| 7 Environmental management              | Pollution control                                                          |
| 8 system                                | Environment Certification, Green technology, Materials used in the supplied components that reduce the impact on natural resources |
| Green Transportation                    | Eco-efficient transportation, Green fuels                                   |
| 9 Occupational health and safety        | Health and safety practices, OHSAS 18001                                   |
| 10 management systems                   |                                                                            |

3. Results and Discussion

3.1 Application of Dematel Method
To find out each sub-criterion has a relationship with other sub-criteria by comparing the stress value (0.0884) with the value of the matrix. If the matrix value is greater than the stress value then the sub-criteria has an influence on other sub-criteria and vice versa if the matrix value is smaller than the stress value then the sub-criteria has no effect on the other sub-criteria. The next step after the total relationship matrix is obtained, namely calculating the vector D and R which is then used to calculate prominence (D + R) and relation (D - R). The value of prominence (D + R) indicates the level of importance of the sub-criteria to the choice of sustainable suppliers, but for the value of the relationship (D - R) shows the causal relationship on the sub-criteria.

### Table 2. Calculation Results of the D - R Vector and the D + R Vector

| Criteria                          | Sub-criteria                        | D    | R    | D-R  | D + R |
|----------------------------------|-------------------------------------|------|------|------|-------|
| Cost/price                       | Product price (PP)                  | 2.0964 | 1.7823 | 0.3140 | 3.8787 |
|                                  | Transportation cost (TC)             | 1.5518 | 1.1661 | 0.3857 | 2.7179 |
|                                  | Payment term (PT)                   | 1.0194 | 1.2923 | -0.2730 | 2.3117 |
|                                  | Duty (D)                            | 0.8948 | 0.7132 | 0.1816 | 1.6080 |
| Delivery                         | On time delivery (OTD)              | 1.8602 | 1.8307 | 0.0295 | 3.6909 |
|                                  | Lead Time (LT)                      | 1.5850 | 1.7856 | -0.2005 | 3.3706 |
| Quality                          | Supplier certification (SC)         | 2.8708 | 1.6803 | 1.1905 | 4.5511 |
|                                  | Chemical purity (CP)                | 2.8740 | 2.1060 | 0.7680 | 4.9801 |
| Production Facilities and Capacity | Supply capacity (SCT)              | 1.4973 | 1.5383 | -0.0410 | 3.0356 |
|                                  | Size of product (SP)                | 0.7750 | 0.7387 | 0.0362 | 1.5137 |
| Service                          | After sales service (AS)            | 1.6040 | 2.1477 | -0.5438 | 3.7517 |
|                                  | Warranty (W)                        | 1.5587 | 2.2408 | -0.6821 | 3.7995 |
| Financial Capability            | Financial stability (FS)            | 1.5215 | 1.8982 | -0.3768 | 3.4197 |
| Pollution production             | Pollution control (PC)              | 1.3967 | 1.8017 | -0.4050 | 3.1984 |
| Environmental management System  | Environment Certification (EC)      | 1.9052 | 1.9724 | -0.0672 | 3.8776 |
|                                  | Green technology (GT)               | 2.3694 | 2.0319 | 0.3375 | 4.4013 |
|                                  | Materials used in the supplied      |       |       |       |       |
|                                  | components that reduce the impact   |       |       |       |       |
|                                  | on natural resources (MAT)          | 1.8566 | 2.0151 | -0.1585 | 3.8717 |
| Green Transportation             | Eco-efficient transportation (ET)   | 1.2269 | 1.3318 | -0.1048 | 2.5587 |
|                                  | Green fuels (GF)                    | 0.9419 | 1.3322 | -0.3903 | 2.2741 |
| Occupational health and          | Health and safety practices (HS)    | 2.2924 | 1.6948 | 0.5976 | 3.9872 |
| safety management systems        | OHSAS 18001 (OH)                    | 1.5195 | 1.5670 | -0.0475 | 3.0865 |

After the decision making hierarchy model is made, the ANP network model is made based on the interrelationship between sub-criteria on the impact diagram map.

### 3.2 Application of ANP Method

The first stage carried out in the sub-chapter is to carry out the process of weighting between criteria and sub-criteria where the input is the result of a paired comparison questionnaire of criteria, sub-criteria and alternatives that are filled in by experts. This data processing uses Super Decision 2.10 software. There are 2 columns in the weighting table, normalized by cluster, which shows the local weights of the sub-criteria and limiting is a global weight between the criteria and sub-criteria that can be seen in table 3. After obtaining the local weights from the sub-criteria, the local weight of the criteria is calculated first. Limiting weights are divided by normalized weights by cluster and then calculating the average in the grouping of sub-criteria according to the criteria, so the results are local criteria weights. Global weights are obtained by multiplying local weights obtained, so that global
weights can be used as a basis in the supplier selection process. Global Weight Criteria, sub-criteria and alternatives can be seen in Table 4.

### Table 3. Local Weight Sub-Criteria

| Sub-criteria | Normalized by Clusters | Limiting |
|--------------|------------------------|----------|
| D            | 0.10108                | 0.012002 |
| PT           | 0.24277                | 0.028827 |
| PP           | 0.61032                | 0.072471 |
| TC           | 0.04583                | 0.005442 |
| LT           | 0.46723                | 0.04027  |
| OTD          | 0.53277                | 0.045919 |
| EC           | 0.38742                | 0.051617 |
| GT           | 0.37229                | 0.0496   |
| MAT          | 0.24029                | 0.032014 |
| FS           | 1                      | 0.048302 |
| ET           | 0.62696                | 0.033368 |
| GF           | 0.37304                | 0.019854 |
| HS           | 0.59854                | 0.068917 |
| OH           | 0.40146                | 0.046224 |
| PC           | 1                      | 0.056438 |
| SP           | 0.02692                | 0.001775 |
| SCT          | 0.97308                | 0.064173 |
| CP           | 0.62097                | 0.158964 |
| SC           | 0.37903                | 0.097028 |
| US           | 0.59038                | 0.039434 |
| W            | 0.40962                | 0.02736  |

### Table 4. Global Weights

| Criteria | Sub-criteria | Alternative | Global Weight |
|----------|--------------|-------------|---------------|
| 0.1187   | 0.1011       | S1 0.0040   | S2 0.0035     | S3 0.0045     |
|          | 0.2428       | S2 0.0097   | S2 0.0084     | S3 0.0108     |
|          | 0.6103       | S3 0.0243   | S2 0.0210     | S3 0.0272     |
| 0.0862   | 0.0458       | S3 0.0018   | S2 0.0016     | S3 0.0020     |
|          | 0.4672       | S3 0.0135   | S2 0.0117     | S3 0.0151     |
|          | 0.5328       | S3 0.0154   | S2 0.0133     | S3 0.0172     |
|          | 0.3874       | S3 0.0173   | S2 0.0150     | S3 0.0194     |
| 0.1332   | 0.3723       | S3 0.02899  | S3 0.3752     | S3 0.0166     |
|          | 0.3349       | S3 0.0144   | S3 0.0186     |
| 0.0483   | 0.2403       | S3 0.0012   | S3 0.0097     |
|          | 1.0000       | S3 0.0120   | S3 0.0120     |
| 0.0532   | 0.6270       | S3 0.0162   | S3 0.0140     |
|          | 0.3730       | S3 0.0100   | S3 0.0125     |
| 0.1151   | 0.5985       | S3 0.0066   | S3 0.0058     |
|          | 0.4015       | S3 0.0231   | S3 0.0259     |
| 0.0564   | 1.0000       | S3 0.0155   | S3 0.0173     |

In this study, supplier selection is not only based on an assessment of its performance, but also considered an unexpected deviation (failure mode) from supplier performance in accordance with the supplier selection criteria that have been determined in the previous stage. At this stage the Failure Mode and Effect Analysis (FMEA) method is used to identify and assess risks associated with unexpected deviations from supplier performance. Each failure mode will be identified the potential impact that occurs if the failure mode occurs (potential effect), then analyze the causes of failure mode (risk cause) and analyze the controls (current control). The workmanship stages in this section consist of identifying failure mode, evaluating severity values, occurrence and detection and calculation of risk priority number (RPN). This identification phase is carried out by means of discussion with experts. There are 8 risks identified from 7 criteria’s supplier selection, i.e. cost / price (increase in raw material prices (R1), increase in shipping costs (R2)), delivery (delay in delivery of raw materials (R3)), quality (purity of raw material compounds not in accordance with standard (R4)), production facilities and capacity (suppliers cannot meet company demand (R5)), service (less responsive supplier response (R6)), pollution production (environmental pollution occurs (R7)), occupational health and safety management systems (Occupational accidents occur at supplier employees (R8)). The results of the risk assessment for each supplier can be seen in table 5. This assessment uses the FMEA 1-10 scale for severity (S), occurrence (O) and detection (D)[10].

This assessment process uses the FMEA approach that has been developed by [9] by using equations 9 through equation 10. One example of calculation of risk to supplier 1 is the delivery criterion (R2) where S = 2, O = 3, D = 5. So the calculation results are R = 6, ep = 1.05 and RPN = 4.350% or 0.04350. RPN calculation results for each supplier can be seen in table 6.
The results obtained by the ANP method are supplier weights that are seen based on the performance or capability of each supplier, while data processing with FMEA is carried out a risk assessment for each supplier that has been previously identified. Both of these results will be input into the calculation in this section by using the equation development that has been done by [9] in equation 12. Risk-discounted score is the final weighting where the weight obtained from ANP will be given a discount based on an assessment of the risks that will occur to each supplier. The following are the results of the calculation of Risk-discounted score which can be seen in table 7.

| Criteria                                      | S1        | S2        | S3        |
|-----------------------------------------------|-----------|-----------|-----------|
| Cost / Price                                  | 0.03524   | 0.02364   | 0.03585   |
| Delivery                                      | 0.02761   | 0.02189   | 0.02407   |
| Production facility                           | 0.04461   | 0.03863   | 0.04999   |
| Quality                                       | 0.01617   | 0.01400   | 0.01812   |
| Service                                       | 0.01782   | 0.01543   | 0.01997   |
| Occupational health and safety management systems | 0.03498   | 0.03253   | 0.03641   |
| Pollution production                          | 0.01890   | 0.01636   | 0.02118   |
| Environmental management system               | 0.02032   | 0.01347   | 0.02317   |
| Financial Capability                          | 0.06786   | 0.06494   | 0.06803   |
| Green Transportation                          | 0.02169   | 0.01826   | 0.01357   |
| Total                                         | 0.29635   | 0.25621   | 0.28464   |

In the process of selecting sustainable suppliers at PT XYZ, it integrates the DEMATEL-ANP and FMEA methods, where the results of the calculation of the RPN on FMEA will be used as a deduction from the weight of the supplier obtained from calculations with DEMATEL-ANP. The greater the RPN value, the greater the deduction for supplier weights. The supplier selection process in this study not only looks at the (positive) performance of the supplier but also looks at the possible risks that will occur to the supplier. So that suppliers who have good performance and have a low risk will be the chosen supplier or the best supplier. The risk-discounted score calculation results into the supplier's final weight by integrating the DEMATEL-ANP and FMEA methods.

| Pemasok 1     | Pemasok 2     | Pemasok 3     |
|---------------|---------------|---------------|
| DEMATEL-ANP   | 0.3349 (rank 2) | 0.2899 (rank 3) | 0.3752 (rank 1) |
| Integrasi DEMATEL-ANP dan FMEA | 0.3179 (rank 1) | 0.2677 (rank 3) | 0.3047 (rank 2) |

If we look at supplier weights using the DEMATEL-ANP method where this method assesses the performance or ability of suppliers to meet supplier selection criteria, supplier 3 is in first place with a weight of 0.3752. Then supplier 1 is in second place with a weight of 0.3349, while supplier 2 is in the last position with a weight of 0.2899. However, there are differences in the results of the integration of DEMATEL-ANP and FMEA, where in the supplier selection process not only considers the performance of the supplier but also considers the risks that will occur. It can be seen in Table 5.1 that supplier 1 gained the largest weight of 0.3179 while supplier 3 came in second with a weight of 0.3047. Even though supplier 1 is second in the supplier's assessment with DEMATEL-ANP, but suppliers have less risk than other suppliers. So that the final result when calculating the integration of
the DEMATEL-ANP and FMEA methods, supplier 1 is in first place. Whereas for supplier 3, even though it has the highest weight but has a high enough risk, it will provide a considerable weight reduction and make supplier position 3 from the first position to become the second position. So it can be concluded that supplier 1 is a supplier that fits the criteria and sub-criteria of supplier selection at PT. XYZ as well as having a low risk too. Whereas for supplier 3, even though it has the highest weight but has a high enough risk, it will provide a considerable weight reduction and make supplier position 3 from the first position to become the second position. So it can be concluded that supplier 1 is a supplier that fits the criteria and sub-criteria of supplier selection at PT. XYZ as well as having a low risk too.

Conclusion

Various types of MCDM methods have been very widely used in previous studies for the process of selecting sustainable suppliers, but very few consider the relationship between the criteria in the selection of sustainable suppliers and in some cases there are decision-making problems that are not structured hierarchically because there are interactions and dependencies between criteria. In addition, the MCDM method still has limitations where in selecting suppliers it is seen from the positive weight or positive performance of the supplier. While suppliers have some risk or deviation from the performance.

Based on the comparison of supplier weights using only the DEMATEL-ANP method and by integrating the DEMATEL-ANP and FMEA method, it can be concluded that there is a change in results. This shows that suppliers who have good performance (biggest weight) do not necessarily have low risk. So in this study suppliers who have good performance and have a low risk will be the chosen supplier or the best supplier.

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