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Supplier Selection Modeling and Analysis in the Metal Casting Industry Using Analytical Hierarchy Process

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Abstract. This study presents a supplier selection problem of a raw material using an analytical hierarchy process. In the existing process, the delivery of raw materials experienced delays and impacted the production process. Therefore, this paper aims to determine the criteria for supplier selection and provide recommendations for the best vendor to be selected from the last request for quotation document. Analytical Hierarchy Process (AHP), as a multi-criteria approach, was utilized in this research, starting from determining criteria, the weight of criteria, and the final score for each supplier. Through discussions with the company's expert, procurement department, and users, as well as a review of the previous studies, this research defined three criteria, each consisting of three sub-criteria. The AHP approach was utilized to evaluate and determine the weights for the three criteria, yielding the following results: quality (62%), price (28%), and delivery (10%). The identified criteria, sub-criteria, and respective weights are subsequently utilized in a supplier selection scenario. Three suppliers of mild steel raw materials were evaluated using the weights of the criteria and sub-criteria obtained. Supplier 1 was selected because of having the higher alternative value of 0.602. The use of AHP in supplier selection is often impractical and contains subjectivity. Therefore, further research can be performed by integrating AHP with other methods, such as weighted scoring, to facilitate further the vendor selection process and integration with other methods, such as fuzzy logic, to reduce subjectivity.

Keywords: AHP, Logistics, Procurement, Supply Chain, Mild Steel Plate.

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1. Introduction

The competition among manufacturing and service industries is increasing rapidly, supported by the development of the science and technology [1]. Companies must provide satisfactory service to consumers and maintain product quality to survive the fierce competition. In addition, to maintain the quality of its product, the company needs to pay attention to the raw materials used in the production process.

The supplier of the raw materials determines the quality of the raw materials. The supplier is a business partner that plays a crucial role in ensuring the availability and quality of raw materials.

Selecting the right supplier according to the company's criteria can generate profit by minimizing costs incurred [2]. Therefore, supplier selection must be performed correctly and carefully to avoid selecting unperformed suppliers [3].

This study used a metal casting company with a make-to-order strategy as a case study. Supplier selection is a critical aspect of the metal casting industry due to its impact on product quality, cost, and productivity [4]. The studied company produces several products, and one of the primary raw materials used is mild steel. In the existing supplier selection method, the decision was solely based on the price of raw material. The supplier selected based on the low-price criteria experienced a delay in delivery, which affected the production process.

Supplier selection can be classified as a multi-criteria decision-making (MCDM) problem, where decision-makers must consider and assess qualitative and quantitative factors [5]. In supplier selection problems, more than one aspect must sometimes be considered [6]. Akarte [7] stated that decision-makers should consider tangible and intangible criteria in supplier selection, such as product development, manufacturing, quality, and cost.

Various methods have been used to address supplier selection problems in the metal industry, such as SWARA and TOPSIS [8], Fuzzy AHP [9], and AHP [10]. In this study, AHP was employed to evaluate the supplier selection problem. A range of studies have demonstrated the effectiveness of the AHP in supplier selection within the metal industry. Tahriri [10] found that AHP can optimize order quantities and reduce the time to select a supplier. Valim [11] and Chhabile [12] compared AHP with other methods, with both studies concluding that AHP is a consistent and effective approach to supplier selection.

Based on the above-mentioned description, this research aims to determine the criteria and sub-criteria in supplier selection. Interview methods and previous literature studies with similar objects were used to determine the criteria and sub-criteria. After the criteria were obtained, the AHP method was used to determine the weight of each criterion and sub-criteria. The weight of criteria contains important information and determines the supplier selection decision. Finally, the criteria and criteria weights were then implemented to evaluate vendor quotations to determine which vendor should be selected by the company.

2. Methods

A range of studies have applied the AHP to the supplier selection problem, emphasizing its ability to consider both qualitative and quantitative criteria. Garoma [13] highlights the importance of AHP in reducing subjectivity and selecting the best vendor. AHP breaks down complex and unstructured problems into components arranged hierarchically. Subjective values are assigned to the components, and the variables that positively influence the situation's outcome are determined [14].

Figure 1 depicts the research flow, consisting of three main steps: the preliminary, data collection and processing, and discussion and conclusion. In the preliminary step, problems and solutions were defined. The author identifies the problems in the company, then addresses them and formulates them. After finding a problem, a literature study was performed by looking for references from books and journals and making observations. The problem raised was about what criteria, sub-criteria, weight of criteria and sub-criteria, and the company's best supplier. The problem was described into its elements, consisting of criteria and alternatives, and arranged into a hierarchical structure.

The data collection and processing stage consists of determining criteria, sub-criteria, and the weight of the criteria. This research used company experts consisting of procurement and users to determine criteria weights through pairwise comparisons. Before the AHP results are used, the consistency ratio

(CR) value is calculated to determine whether it met the standard of less than or equal to 0.1. The pairwise comparison is repeated if the CR calculation results obtained a value of more than 0.1.

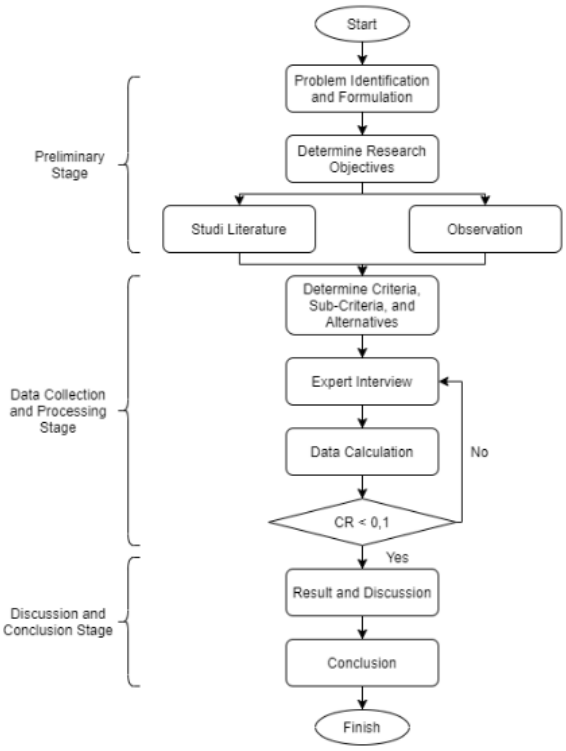

Figure 1. *Research Flow*

3. Results and Discussion

3.1 Determining the Criteria and Sub-Criteria

Many previous studies have applied the AHP approach to select metal casting suppliers and identify the main criteria and sub-criteria. Soepardi [16] and Wang [17] highlight the importance of product quality, cost, and manufacturing capability. In addition, Tahriri [10] and Lin [18] further proposed the trust, net price, and delivery rate as the main criteria. Therefore, previous studies highlight the main criteria: quality, cost, and delivery rate. To ensure relevance to the observed company, this study determined criteria by discussion with related stakeholders such as the procurement department and users. This discussion verifies the importance of the three criteria: quality, cost, and delivery rate. In addition, the discussion also highlights the sub-criteria for each defined criterion.

3.1.1 Quality (A)

Quality refers to a product or service characteristic that supports its ability to satisfy customer needs [19]. Quality represents a company's effort to differentiate its products from competitors to make them more desirable or unique. Quality is used as a criterion because in selecting suppliers, the quality of raw materials affects the quality of the product. Furthermore, the quality criteria are broken down into three sub-criteria as follow:

1. **Quality standard (A1)**
   Quality standards are used to assess and measure the level of quality or adequacy of a product. Quality standards set specific standards or limits that must be met for the product to be considered to meet the desired level of quality.
2. **Product specification conformance (A2)**

The conformity of product specifications refers to the extent to which the product meets the specifications or requirements previously set.

3. **Completeness of documents (A3)**
   Completeness refers to how documents related to checking or testing a product have been prepared and meet predetermined requirements.

3.1.2 Price (B)

A price is a monetary unit exchanged to obtain ownership rights [20]. Price is used as a criterion because competitive prices from suppliers can help companies control production costs to increase companies' profitability. In the price criteria, 3 sub-criteria were defined:

1. **Price fluctuation rate (B1)**
   The level of price fluctuation refers to how often there is a change or instability in the supplier's price. A high level of price fluctuation can cause uncertainty in budget planning and supply chain management.
2. **Price Level (B2)**
   Price level is the price charged by a supplier for a product. It includes the direct price of the purchased goods and additional costs such as shipping or administrative costs.
3. **Price Flexibility (B3)**
   Price flexibility means suppliers are willing to negotiate or provide price adjustments in contractual agreements. Suppliers' flexibility on price can make reaching a mutually beneficial agreement easier.

3.1.3 Delivery (C)

Delivery is part of logistics operations to distribute goods and services from producers to consumers efficiently and accurately [21]. The reason for using delivery as a criterion is that it helps companies mitigate risk, improve operational efficiency, and provide better customer service. In the delivery criteria, there are 3 sub-criteria defined as follows:

1. **Delivery promptness (C1)**
   Delivery promptness refers to the supplier's ability to deliver products according to the agreed schedule.
2. **Lead time (C2)**
   Lead time can be described as the time required from the time of order until the customer receives the product. Suppose the goods are delivered within the delivery tolerance period. In that case, no penalty fee is charged to the vendor, thus providing flexibility for vendors and buyers to overcome the uncertainty of delivery mechanisms and transportation times [22].
3. **Delivery flexibility (C3)**
   Delivery flexibility is to adjust the delivery schedule according to the needs of the customer company. Flexible suppliers can respond quickly to changes in demand or emergencies.

3.2 AHP Structure

Based on the criteria and sub criteria defined in the previous step, Figure 3 illustrated the AHP structured consisting of criteria, sub criteria and alternatives. In the hierarchical structure, the main goal is placed at the first level, the criteria obtained are placed at the second level, the sub-criteria at the third level, and the alternatives at the last level. In this study, the three supplier was used as supplier alternatives and evaluated using pre-defined criteria and sub criteria to get the best supplier.

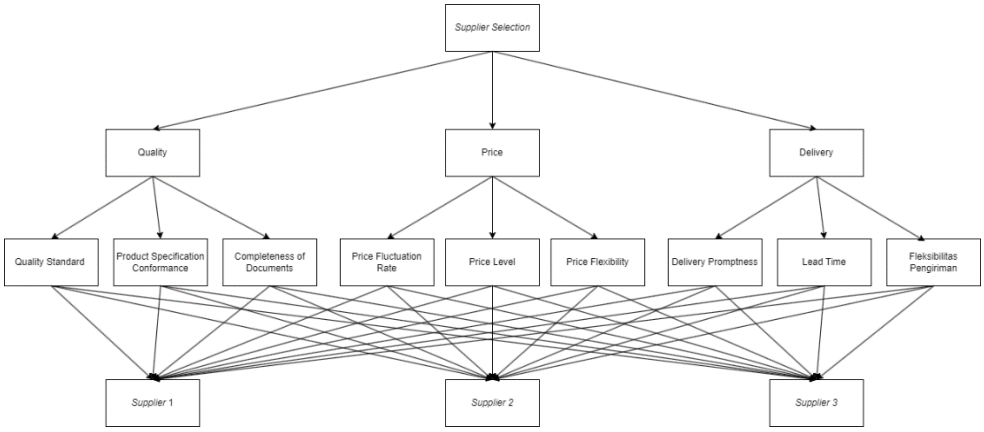

Figure 2. *Hierarchical Structure of Criteria, Sub-criteria and Alternative*

The hierarchical model is subsequently utilized to develop a pairwise comparison questionnaire. This study involved procurement and users as respondents, utilizing the scale presented in Table 1. The consensus approach is used to determine the value of pairwise comparisons.

The Consistency Ratio value of the comparison results was initially assessed using Equation 2. If the CR value is less than or equal to 1, the AHP evaluation can be utilized for subsequent processing. Table 2 illustrates an example of computations for pairwise comparison of criteria. Table 3 provides a summary of the CR values for all pairwise comparisons.

Table 1. *Pairwise Comparison Among Suppliers*

Criteria	Quality	Price	Delivery	Quality	Price	Delivery	1	2	3	4 = 3/2	5 = Sum 4/Sum 1	6 = (5 - Sum 1)/(Sum 1- 1)	7	8 = 6/7
							Total Weight Matrix	*eugen vector*	Perkalian Matriks	*Eugen Value*	*λ maks*	*CI*	*IR*	*CR*
Quality	1	3	5	0,6522	0,7059	0,5000	1,8581	0,619352	1,954135	3,155127	3,086690971	0,043345485	0,58	0,074734
Price	1/3	1	4	0,2174	0,2353	0,4000	0,8527	0,284228	0,876357	3,083283				
Delivery	1/5	1/4	1	0,1304	0,0588	0,1000	0,2893	0,096419	0,291347	3,021662				
Total	1,53333333	4,25	10	1	1	1	3	1	3,121839	9,260073				

Table 2 shows the weights for the Quality, Price, and Delivery criteria, which are 0.62, 0.28, and 0.10, respectively. The pairwise comparison results are consistent because the CR is less than or equal to 0.1. Thus, the weighting results can be used for further analysis. The CR evaluation for all pairwise comparisons is shown in Table 3, which indicates that all pairwise comparisons have been consistent.

Table 2. *Consistency Ratio (CR) for all pairwise comparison*

No	Pairwise Comparison	CR
1	Main criteria	0,074
2	Sub criteria: Quality	0,093
3	Sub criteria: Price	0,046
3	Sub criteria: Delivery	0,015
4	Alternative against Sub criteria: Quality	0,081
5	Alternative against Sub criteria: Price	0,015
6	Alternative against Sub criteria: Delivery	0,074

3.3 Result and Discussion

Table 4 presents the result of the AHP approach. Based on the three criteria defined in the previous step, Quality (A) was the criterion with the highest weight (0.62). This number means that the quality aspect is far superior to the other criteria: Price (B) and Delivery (C). In a detailed analysis of Quality criteria, Product specification conformance (A2) is the sub-criteria with the highest weight. This number

indicated that conformity with the predefined specification is the main criterion in supplier selection. The value of Alternative Weight Evaluation Supplier 1 is 0.602, Supplier 2 is 0.288, and Supplier 3 is 0.110. Therefore, it can be concluded that based on these three alternatives, Supplier 1 was chosen because it has the highest Alternative Weight Evaluation value of 0.602.

Table 1 AHP Result

	Attribute									***Alt. Weight Evaluation***
	A			B			C			
	0,62			0,28			0,10			
Attribute weight	*A1*	*A2*	A3	*B1*	*B2*	*B3*	*C1*	*C2*	*C3*	
	0,36	*0,52*	0,12	0,25	0,58	0,16	0,62	*0,24*	*0,13*	
	Alternative									
Supplier 1	0,62	0,61	0,54	0,61	0,62	0,52	0,52	0,60	0,51	0,60
Supplier 2	0,28	0,28	0,34	0,28	0,23	0,33	0,33	0,27	0,36	0,28
Supplier 3	0,09	0,09	0,11	0,09	0,13	0,14	0,14	0,11	0,12	0,11

Further analysis can be performed by evaluating the sensitivity and integrating AHP with another method. Ishak [23] applied AHP in real-world scenarios, using AHP-TOPSIS to determine the best wire rod supplier. AHP can also be integrated with the weighted scoring method in determining the best supplier. AHP is used to determine criteria and criteria weights, while each vendor is given a value for each criterion. The weighted score is then obtained by multiplying the weight of the criteria by the vendor's score. Through this integration, supplier selection becomes easier for companies to do.

4. Conclusion

This research aims to model and analyze supplier selection for metal-casting raw materials using the AHP method. Based on previous research and discussions with procurement and users, the criteria identified are quality, price, and delivery. Each criterion is further elaborated in the three sub-criteria: quality standards, conformity to product specifications, completeness of checking documents, level of price fluctuations, price level, price flexibility, delivery accuracy, lead time, and delivery flexibility. The evaluation results with AHP obtained weights for each main criterion, which are 0.62, 0.26, and 0.10, and are used for supplier selection. The results of supplier selection using AHP showed that supplier 1 is the best supplier with a weighted value of 0.602. The results of the criteria and criteria weights from this research can be used by companies that use metal as raw materials to determine the best supplier. The use of AHP in supplier selection is often impractical and contains subjectivity. Therefore, further research can be performed by integrating AHP with other methods, such as weighted scoring, to further facilitate the vendor selection process and integration with other methods, such as fuzzy logic, to reduce subjectivity.

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