

# **An Integrated AHP–Mathematical Programming Approach for Make-or-Buy Decisions in Pile Driving Machine Components**

**Bilge Öztürk, Syed Shah Sultan Mohiuddin Qadri and Şevval Ertan**

Department of Industrial Engineering  
Çankaya University  
Ankara, Türkiye

[bilgeeeozturk15@gmail.com](mailto:bilgeeeozturk15@gmail.com), [syedshahsultan@cankaya.edu.tr](mailto:syedshahsultan@cankaya.edu.tr), [sevvalertan@gmail.com](mailto:sevvalertan@gmail.com)

## **Abstract**

The problem of decision making in the real-life situations that are complex is difficult because it requires simultaneous consideration of the alternatives with various benefits and drawbacks so as to determine the most appropriate choice. The main aim of the research is to critically compare three options based on various criteria of varying levels of significance, in regard to essential parts and components used in the pile-driving machines in a strategic procurement process. In this context, the decision problem was hierarchically organized, and the Analytic Hierarchy Process (AHP) was used in order to estimate relative importance weights of the criteria. These weights were used to evaluate the alternatives of each machine part and rank them. The results of the analysis indicate that there are considerable differences between the options and that some of the criteria have a more decisive impact on product-related choices. Moreover, a mathematical optimization model was developed by integrating the priority scores as calculated by the AHP into the objective function, thus arriving at the best decision within the constraints of operational capacity. This strategy provides a deliberate, clear, and realistic decision support system that strikes a balance between cost and strategy and resource constraints.

## **Keywords**

Make-or-Buy Decision, Analytic Hierarchy Process (AHP), Multi-Criteria Decision Making, Mathematical Optimization and Capacity Constraints.

## **1. Introduction**

Make-or-buy decisions are one of the fundamental strategic issues in manufacturing systems, which have a decisive impact on the long-term competitive advantage of a company. Whether to produce a part (in-house), to buy it (outsourcing), or to use a combination of both (hybrid) requires a comprehensive evaluation because it cannot be determined only by the cost factor. Rather, several factors, such as quality, production capacity, technical capability, flexibility, and lead time in delivery, should be considered at the same time. Furthermore, the high rate of technological change has increased the complexity of such decisions, which has led to the need to have systematic analytical frameworks (Nazir et al., 2022).

The strategic sourcing literature asserts that make-or-buy decisions must be aligned with core competencies and long-term strategic goals of a firm. Strategic sourcing models suggest analytic, stepwise assessment procedures to determine what actions should be kept in-house and what are to be outsourced (Taş, 2025). Reshoring and relocation studies argue that sourcing decisions should go beyond the cost factor to include risk, flexibility, and strategic positioning dimensions (Sequeira et al., 2021; Sequeira et al., 2022). In the context of new-product introduction, the structured make-buy systems emphasize the critical role of capacity limitations, supplier strengths, and time-to-market factors in

sourcing strategies (Reddy et al., 2021). Taken together, these publications confirm that make-or-buy decisions are multi-dimensional strategic arrangements and not basic operation acquisition decisions.

The issue of make- or -buy decisions has also been considered under the maintenance planning domain on multi-criteria methodology. When evaluating the in-house and outsourcing options of maintenance policies, researchers highlight the importance of considering reliability and performance indicators in addition to cost benefits (Ortali et al., 2024). Similarly, the studies of application-maintenance offshoring emphasize the necessity to collectively consider risk, cost, and performance metrics (Rahman et al., 2021). In this context, the make-or-buy problem was hierarchically organized in the first Analytic Hierarchy Process (AHP)-based decision-support models, which assign the weights of criteria systematically and, therefore, enhance the transparency of the decisions (van de Water and van Peet, 2006).

Among the various Multi-Criterion Decision-Making (MCDM) methods, the AHP has had a massive following owing to its ability to organize decision problems in a hierarchical manner and determine the relative significance of criteria through pair-wise comparisons (Sharma et al., 2022; Sarjono et al., 2020). The theoretical basis and wide applicability of AHP have been well examined in the literature (Tanwar et al., 2020). The AHP-TOPSIS-based methods have been used to rank alternatives in the field of outsourcing service-provider selection based on their closeness to an ideal solution (Quispe-Atanacio et al., 2026). Integrations of fuzzy AHP with fuzzy TOPSIS can be used to support more flexible assessments when faced with uncertainty (Sequeira et al., 2022; Kilttila et al., 2026). Entropy-weighted AHP and TOPSIS models that combine both subjective and objective weighting schemes are also used to improve the robustness of the decision (Chen, 2020). Taken together, these works support the idea that the AHP-based methods are effective instruments of strategic sourcing and outsourcing decisions.

However, the literature warns that ranking alternatives might not be sufficient, but operational constraints should be included. Multi-objective and multi-period mathematical programming models consider make- or -buy decisions when there are demand and capacity constraints and resource allocation constraints (Zahedirad et al., 2025). The models that use optimization and incorporate the quality-improvement and cost factors shed more light on the necessity to consider the strategic preferences along with the operational feasibility (Rosyidi et al., 2020). These studies show that the combination of multi-criteria evaluation and mathematical modelling can improve the quality of decisions. Moreover, the combination of AHP and goal-programming and other quantitative methods allows the trade-off between several objectives in constraint models (Tanwar et al., 2020).

Despite the large amount of literature on make-or-buy and outsourcing decision-making, there is little literature that focuses on the combined analysis of in-house, outsourcing, and hybrid options in critical parts used in heavy-industrial equipment with an AHP-based multi-criteria framework and a mathematical model that takes into consideration operational constraints. The critical components of the pile-driving machines work under extreme mechanical loads, which directly influence the durability, maintenance rate, and reliability of the operation. As a result, the choice under consideration is not only a supplier-selection issue but a strategic choice of the production process.

## **1.1 Objectives**

This paper aims to create a combined decision-support model of make-or-buy decisions regarding key parts used in pile driving machines by incorporating the AHP and a mathematical optimization model that is operated under operational limits. The research compares three options of production strategies: (i) in-house production, (ii) outsourcing, and (iii) a combination of both (hybrid), on the basis of critical components used in pile-driving machines through the AHP approach, and hence, a priority ranking is determined on each component. Depending on the calculated priority values, the most suitable production strategy is chosen. Moreover, the priority scores achieved in the multi-criteria analysis are integrated, on the selected elements (hybrid components), into a mathematical optimization model that incorporates capacity and operational limitations, which allows analysing the viability of the selected strategy (between the in-house and outsourcing). This way, the comparative excellence of strategic preferences and production realities are collaboratively analyzed in a systematic decision-support system.

## **2. Methods**

### **2.1. AHP Methodology**

This section outlines the methodology used to determine the most suitable alternative. A multi-criteria decision-making method based on the AHP is employed.

### Step 1. Determination of Criteria

The criteria used in this research were outlined through the analysis of both strategic and operational requirements that are relevant in the choice of production strategies in a pile-driving equipment company. The models of decision making of the in-house, outsourcing, and hybrid production strategies were analysed, and the cost, capacity, risk, and sustainability were found to be the most recurrent and influential factors. As a result, nine major criteria, including quantitative and qualitative ones, were chosen. These criteria cover the economic, operational, and sustainability aspects of the issue in a comprehensive way. Table 1 shows the chosen AHP criteria along with their description and preferences.

Table 1. Criteria Used in the AHP Analysis

| Criteria              | Description                                                                                 | Preference (min/max) |
|-----------------------|---------------------------------------------------------------------------------------------|----------------------|
| Cost                  | Total annual production cost.                                                               | Min                  |
| CAPEX                 | The amount of investment required for new equipment.                                        | Min                  |
| Capacity Usage        | The ratio of machine capacity is actually used relative to the current production capacity. | Max                  |
| Lead Time             | Time from order to delivery.                                                                | Min                  |
| Scrap Risk            | The proportion of defective or unusable products generated during the production process.   | Min                  |
| Flexibility           | Ability to adapt to changes or uncertainties.                                               | Max                  |
| Supplier Dependency   | Level of dependence on external suppliers.                                                  | Min                  |
| Customer Satisfaction | Customer feedback and service quality level.                                                | Max                  |
| Environmental Impact  | Energy consumption and emission levels.                                                     | Min                  |

### Step 2: Defining the AHP Approach

The AHP method enables the hierarchical arrangement of criteria and alternatives in decision-making problems. The hierarchical structure of the AHP used for this study is shown in Figure 1.

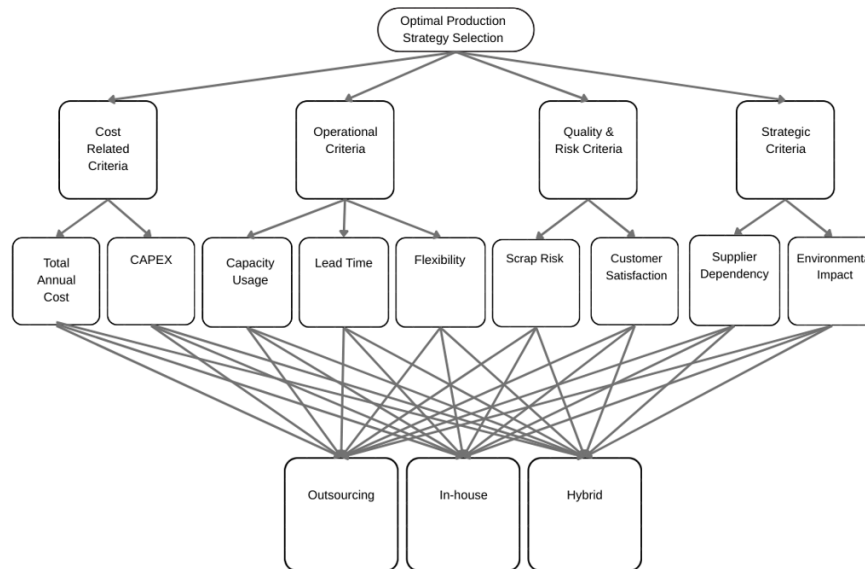


Figure 1. The Hierarchical Structure

### Step 3: Construct the pairwise comparison matrix.

In this step, the relative importance of nine criteria was evaluated using the pairwise comparisons based on Saaty's (1980) 1-9 fundamental scale, as presented in Table 2.

Table 2. Saaty's Fundamental Scale

| Saaty's fundamental scale | Definition             | Explanation                                                                                                      |
|---------------------------|------------------------|------------------------------------------------------------------------------------------------------------------|
| 1                         | Equal importance       | Two elements contribute equally to the objective.                                                                |
| 3                         | Moderate importance    | One element is slightly more important than the other.                                                           |
| 5                         | Strong importance      | One element is clearly more important than the other.                                                            |
| 7                         | Very strong importance | One element is much more important than the other.                                                               |
| 9                         | Extreme importance     | One element is absolutely more important than the other.                                                         |
| 2,4,6,8                   | Intermediate values    | Used to express compromise between the above judgments.                                                          |
| $1/a_{ij}$                | Reciprocal values      | If element i has one of the above numbers compared with j, then j has the reciprocal value when compared with i. |

The values of the pairwise comparison were determined using a ratio-based approach. Since the model uses both quantitative and qualitative variables, the min-max normalization method was used to transform all the criteria to a similar scale that is between 0 and 1. This was done on criteria where the larger the nominal value, the better the performance (1) and criteria where the smaller the nominal value, the better (2). By so doing, all normalized values have a consistent direction of preference, and higher scores have a consistent meaning of better performance.

The pairwise comparison matrix  $I_{ij}$  was constructed using the ratio of the normalized performance values for each criterion, as defined in Equation (3). When  $I_{ij} > 1$  indicates that criterion i is more important than criterion j, while  $I_{ij} < 1$  indicates the opposite. This method will ensure the establishment of an objective matrix that will not be based on subjective judgments.

$$N_{ij} = \begin{cases} \frac{x_i - \min(x)}{\max(x) - \min(x)}, & (1) \\ \frac{\max(x) - x_i}{\max(x) - \min(x)}, & (2) \end{cases}$$

$$I_{ij} = \frac{N_i}{N_j} \quad (3)$$

This ratio was converted using the scale presented in Table 2, as shown in Equation (4).

$$a_{ij} = \begin{cases} 1, & I_{ij} = 1 \\ 3, & 1 < I_{ij} \leq 1.25 \\ 5, & 1.25 < I_{ij} \leq 1.5 \\ 7, & 1.5 < I_{ij} \leq 2 \\ 9, & I_{ij} > 2 \end{cases} \quad (4)$$

In order to make the pairwise comparisons consistent, the performance ratios were compared with the scale presented in Table 2. The threshold values on this scale indicate the following levels of preference: small, moderate, strong, very strong, and extreme, respectively. And  $a_{ji} = \frac{1}{a_{ij}}$  is used when criterion j is more important than criterion i. All the pairs of quantitative and qualitative criteria were treated in the same way. Accordingly, for n criteria  $C_1, C_2, \dots, C_n$  a square pairwise comparison matrix  $A = [a_{ij}]$  was built as indicated in Equation (5).

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & a_{23} & \cdots & a_{2n} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \frac{1}{a_{3n}} & \cdots & 1 \end{bmatrix} \quad (5)$$

#### Step 4: Normalization of the Pairwise Comparison Matrix.

For normalization, the sum of every column (6) was initially computed in the pairwise comparison matrix, and then each element in the matrix was divided by the total value of its column to obtain the normalized matrix, as indicated in Equation (7).

$$S_j = \sum_{i=1}^n a_{ij} \quad (6)$$

$$a'_{ij} = \frac{a_{ij}}{S_j} \quad (i,j=1,2,\dots,n) \quad (7)$$

$S_j$  represents the total sum of the  $j^{th}$  column, and  $a'_{ij}$  denotes the normalized element of the matrix.

#### Step 5: Calculate the Priority Weight.

After the pairwise comparison matrix was normalized, the priority weights ( $w_i$ ) for each criterion, the value was calculated as the average of the normalized values in the respective row, as shown in Equation (8).

$$w_i = \frac{1}{n} \sum_{j=1}^n a'_{ij} \quad (8)$$

This provides an approximate eigenvector solution representing the relative importance of each criterion.

#### Step 6: Consistency Check.

In order to confirm the reliability of the pairwise comparison evaluations, a consistency analysis of matrix A was done. The maximum eigenvalue ( $\lambda_{max}$ ) is first calculated through Equation (9), and then the Consistency Index (CI) is obtained through Equation (10). Subsequently, the Consistency Ratio (CR) is calculated using Equation (11) and using the Random Index value from Table 3 to assess whether the overall consistency of the comparison matrix is at an acceptable level. According to Saaty (1980), if  $CR < 0.10$ , the comparisons are considered consistent.

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^n \left( \frac{\sum_{j=1}^n a_{ij} w_j}{w_i} \right) \quad (9)$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (10)$$

$$CR = \frac{CI}{RI} \quad (11)$$

Table 3. Random Index (RI) values depending on the number of criteria (Saaty, 1980)

| n  | 1 | 2 | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13   | 14   | 15   |
|----|---|---|------|------|------|------|------|------|------|------|------|------|------|------|------|
| RI | 0 | 0 | 0,58 | 0,90 | 1,12 | 1,24 | 1,32 | 1,41 | 1,45 | 1,49 | 1,51 | 1,53 | 1,56 | 1,57 | 1,59 |

#### Step 7: Pairwise Comparison of Alternatives.

After calculating the weights of the criteria, each alternative was assessed against each of the criteria based on the scale shown in Table 2. Based on this, pairwise comparison matrices were created separately on each criterion, and the consistency of the comparisons was verified with the help of the method mentioned in Step 6.

#### Step 8: Aggregation of Local Weights and Final Ranking of Alternatives.

At this stage, the total priority values for each alternative are calculated by multiplying the local priorities by the corresponding criterion weights and adding the results, as illustrated in Equation (12).

$$S_i = \sum_{j=1}^n w_j \times v_{ij} \quad (12)$$

where

- $S_i$  = overall score of alternatives  $i$ ,
- $w_j$  = weight of criterion  $j$ ,
- $v_{ij}$  = local priority of alternative  $i$  under criterion  $j$ .

The alternative with the highest score  $S_i$  was considered the most appropriate production strategy.

Moreover, during the second stage of this study, a mathematical model was developed to optimize the distribution of the hybrid options.

## **2.2. Allocation of Hybrid Alternatives Using Mathematical Modelling**

On the whole, the AHP analysis determines the most appropriate alternatives to all components. The hybrid sourcing strategy is confirmed to be suitable to particular parts as shown in Figure 2. Figure 2 shortens the parts to Vibroflotation Probe Tip (VPT), Jaw Pins & Bushing (JPB), and Jaw Teeth / Grip Segments (JTG). To make this hybrid strategy operational, a Mixed-Integer Programming (MIP) model was developed to determine the optimal mix between in-house production and outsourcing.

The goal is to minimize a weighted composite measure of the total production cost, an AHP-based preference penalty to maintain consistency with strategic priorities, and a deviation term from predefined target in-house production ratios, formulated within a goal programming framework. The predefined target ratios were assumed to be 35% for VPT, 55% for JPB, and 70% for JTG. These targets are implemented to represent strategic production choices and prevent the extent of allocation, thus supporting a regulated hybrid sourcing framework.

The model is limited by the demand satisfaction and in-house capacity constraint, and it takes into consideration the availability of machines and labor. The demand for each component was assumed to be fixed at 1000 units annually. Machine capacity was limited to 2160 hours, while labor availability was restricted to 1960 hours per year, which is calculated using the standard work schedules. To further guarantee the balanced dual-sourcing policy and exclude complete reliance on one sourcing option, there are lower and upper limits on the in-house production shares, with minimum and maximum limits of 20% and 80%, respectively.

The model parameters are based on realistic sectoral benchmarks. Component-level unit costs reflect representative production and outsourcing prices, while machine and labor processing times capture the relative technical complexity of each part. The weighting parameters ( $\lambda$  and  $\mu$ ) are adjusted to attain an ideal compromise between economic efficiency and the AHP-based strategic factors.

### **Sets**

$P$ : Set of hybrid parts (VPT, JPB, JTG)

$I$ : Set of production alternatives (outsource, in – house)

### **Parameters:**

$D_p$ : Annual Demand (pieces/year)

$C_{pi}$ : Unit production cost of part  $p$  under alternative  $i$  (€/piece)

$T1_p$ : Machine processing time per unit for in-house production (hours/piece)

$T2_p$ : Labor processing time per unit for in-house production (hours/piece)

$H_{machine}$ : Annual available machine time

$H_{labor}$ : Annual available labor time

$\lambda$ : Weight of the AHP penalty in the objective function

$penalty_{pi}$ :  $1 - score_{pi}$ : AHP penalty coefficient per unit

$score_{pi}$ : AHP score of alternative  $i$  for part  $p$

$minIN_p$ : Minimum allowed in-house share

$maxIN_p$ : Maximum allowed in-house share

$targetIN_p$ : Target in-house production ratio

$\mu$ : Weight of deviation from the target share

### **Decision Variables:**

$y_{pi}$ : Annual quantity of part  $p$  under alternative  $i$  (piece/year)  
 $d_p^+$ : Positive deviation from the target in-house quantity  
 $d_p^-$ : Negative deviation from the target in-house quantity

$$\text{Minimize } Z = \sum_{p \in P} \sum_{i \in I} C_{pi} y_{pi} + \lambda \sum_{p \in P} \sum_{i \in I} \text{penalty}_{pi} y_{pi} + \mu \sum_{p \in P} d_p^+ + d_p^- \quad (1a)$$

$$\sum_{i \in I} y_{pi} = D_p \quad \forall p \in P \quad (2a)$$

$$\sum_{p \in P} T1_p y_{pin-house} \leq H_{machine} \quad (3a)$$

$$\sum_{p \in P} T2_p y_{pin-house} \leq H_{labor} \quad (4a)$$

$$y_{pin-house} - \text{target} IN_p D_p = d_p^+ - d_p^- \quad \forall p \in P \quad (5a)$$

$$y_{pin-house} \geq \text{min} IN_p D_p \quad \forall p \in P \quad (6a)$$

$$y_{pin-house} \leq \text{max} IN_p D_p \quad \forall p \in P \quad (7a)$$

$$y_{pi} \geq 0, d_p^+ \geq 0, d_p^- \geq 0 \quad \forall p \in P, \forall i \in I \quad (8a)$$

The objective in Model (1a) aims at minimizing a weighted composite criterion, which includes the total cost of production, an AHP-based preference penalty, and a deviation penalty, in comparison to pre-specified in-house production ratios. The total production cost represents component-related unit costs: the in-house unit costs are fixed at €52, €50, and €49 in the case of VPT, JPB, and JTG, respectively, and the outsourcing unit costs are €74, €72, and €71. The AHP penalty term is defined as  $\text{penalty}_{pi}$ :  $1 - \text{score}_{pi}$ , whereby alternatives with higher AHP scores receive lower penalty values. The weighting parameter  $\lambda$  (set to 200) ensures that the strategic priorities generated by AHP have a significant impact on the allocation decisions. A deviation term weighted by a parameter  $\mu$  (set to 10) which punishes non-conformance to the target in-house production ratios in a goal-programming model; the term is used to reduce extreme allocations and support a moderate hybrid production policy. The demand constraint (2a) imposes the requirement to satisfy the annual demand  $D_p$  of 1000 units per component by the amount of units produced in-house and outsourced cumulatively. The machine capacity constraint (3a) represents the total annual operating time available for in-house production  $H_{machine}$  (2160 hours). Machine processing times per unit are 1.8 hours for VPT, 1.4 hours for JPB, and 1.2 hours for JTG. The labor capacity constraint (4a) constrained the workforce to 1960 hours with the respective labor processing time of 1.1, 1.0, and 0.9 hours per unit. Constraint (5a) connects actual in-house production  $y_{pin-house}$  with the target ratio that is pre-determined by using positive and negative deviation variables  $d_p^+$  and  $d_p^-$ . The lower and upper limits on the in-house production of each component in constraints (6a) and (7a) guarantee a viable dual-sourcing model and avoid the possibility of overreliance on a single sourcing option. Lastly, Constraint (8a) is the non-negativity of all production and deviation variables  $y_{pi}, d_p^+, d_p^-$ . Overall, the model assigns limited in-house capacity preferentially to components that have higher AHP-based strategic importance and operational efficiency, while outsourcing acts as a complementary process to meet demand when binding capacity limits are reached.

### 3. Results and Discussion

The results of the AHP analysis show that there is a strong distinction in the relative weight that is assigned to the nine criteria in the product categories under study. This distinction implies that the processes of product-based decision-making differ depending on the technical organization and production needs of every product. Generally, product evaluation is dominated by economic and quality-oriented criteria. Most products have been given high weights on criteria like total annual cost, scrap risk, and capacity usage; thus, the importance of cost efficiency, quality assurance, and operational performance in the selection of production strategies has been emphasized as presented in Table 4.

Table 4. Criteria Weights Obtained from AHP for Each Component

| <i>Criteria</i>       | <i>Hydraulic Cylinder</i> | <i>Electrical Control Cabinet</i> | <i>Vibroflotation Probe Tip</i> | <i>Jaw Holder Wear Plate</i> | <i>Jaw Pins &amp; Bushing</i> | <i>Jaw Teeth / Grip Segments</i> | <i>Hydraulic Manifold Block</i> | <i>Clamp Body / Jaw Housing</i> |
|-----------------------|---------------------------|-----------------------------------|---------------------------------|------------------------------|-------------------------------|----------------------------------|---------------------------------|---------------------------------|
| Total Annual Cost     | 0.34                      | 0.23                              | 0.15                            | 0.16                         | 0.13                          | 0.16                             | 0.14                            | 0.24                            |
| Scrap Risk            | 0.09                      | 0.11                              | 0.22                            | 0.23                         | 0.23                          | 0.23                             | 0.29                            | 0.09                            |
| Capacity Usage        | 0.10                      | 0.06                              | 0.05                            | 0.06                         | 0.05                          | 0.05                             | 0.05                            | 0.07                            |
| CAPEX                 | 0.19                      | 0.13                              | 0.08                            | 0.09                         | 0.08                          | 0.09                             | 0.08                            | 0.15                            |
| Customer Satisfaction | 0.05                      | 0.08                              | 0.19                            | 0.13                         | 0.19                          | 0.15                             | 0.16                            | 0.11                            |
| Lead Time             | 0.09                      | 0.16                              | 0.09                            | 0.11                         | 0.12                          | 0.10                             | 0.09                            | 0.10                            |
| Flexibility           | 0.06                      | 0.11                              | 0.09                            | 0.11                         | 0.09                          | 0.11                             | 0.10                            | 0.08                            |
| Supplier Dependency   | 0.05                      | 0.08                              | 0.05                            | 0.06                         | 0.08                          | 0.08                             | 0.05                            | 0.09                            |
| Environmental Impact  | 0.03                      | 0.03                              | 0.08                            | 0.05                         | 0.03                          | 0.05                             | 0.04                            | 0.05                            |

Also, Table 5 shows the computed Consistency Ratios (CR) of the main criteria matrix and all the component-based pairwise comparison matrices. All values are less than the acceptable threshold of 0.10, hence validating the consistency of the judgments.

Table 5. Consistency Ratio (CR) Values for Component-Based Pairwise Comparison Matrices

| <b>Component</b>           | <b>CR</b> |
|----------------------------|-----------|
| Hydraulic Cylinder         | 0.092     |
| Electrical Control Cabinet | 0.012     |
| Vibroflotation Probe Tip   | 0.015     |
| Jaw Holder Wear Plate      | 0.011     |
| Jaw Pins & Bushing         | 0.015     |
| Jaw Teeth / Grip Segments  | 0.014     |
| Hydraulic Manifold Block   | 0.021     |
| Clamp Body / Jaw Housing   | 0.021     |

Table 6 groups components into two major categories based on their production complexity and physical dimensions. This classification is used as a basis in the interpretation of the variances in the criterion weights that are shown in Table 4.

Table 6. Classification of Components Based on Types and Characteristics

| <b>Parts</b>               | <b>Type</b>          |
|----------------------------|----------------------|
| Hydraulic Cylinder         | Larger/ Standardized |
| Electrical Control Cabinet | Larger/ Standardized |
| Vibroflotation Probe Tip   | Complex and Delicate |
| Jaw Holder Wear Plate      | Larger/ Standardized |
| Jaw Pins & Bushing         | Complex and Delicate |
| Jaw Teeth / Grip Segments  | Complex and Delicate |
| Hydraulic Manifold Block   | Complex and Delicate |
| Clamp Body / Jaw Housing   | Larger/ Standardized |

After calculating the weight of the criterion, final AHP scores and rankings relating to the production strategy alternatives were calculated on each component. Figure 2 shows the final results of the production strategies in the various components.

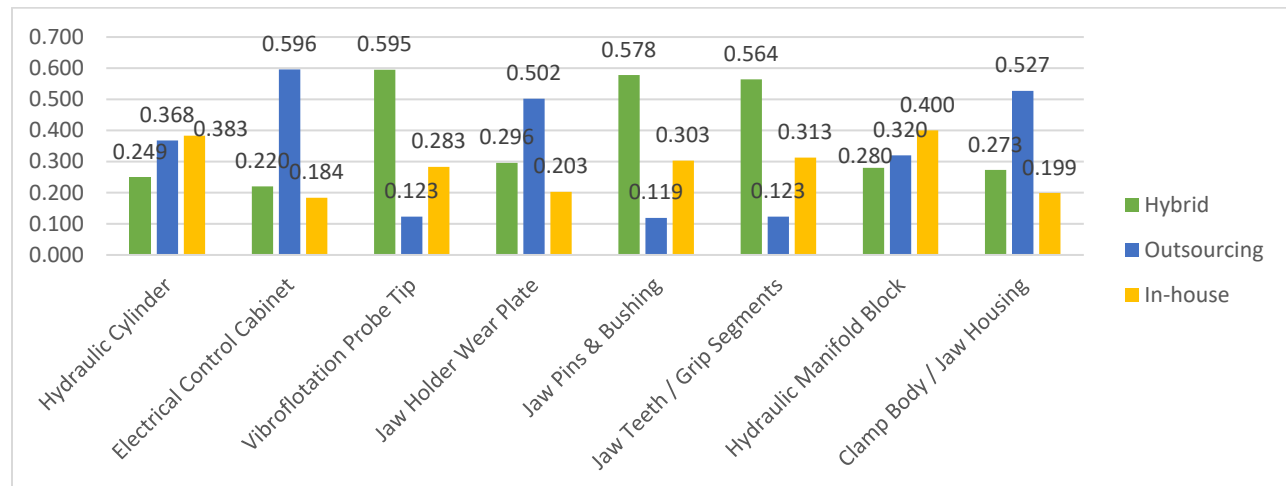


Figure 2. Comparison of Final Scores for Outsourcing, In-house, and Hybrid Production Strategies Across Components

A combination of the findings in Figure 2 indicates that not all products have the same weighting for all the criteria. In more complex and delicate parts (as classified in Table 6), the scrap risk and customer satisfaction criteria are more important, while in larger parts (Table 6), criteria such as total annual cost, CAPEX, and capacity usage are more prominent. On the other hand, lead time, flexibility, dependency on suppliers, and environmental impact have a secondary position in the general model. These differences explain why different production approaches, such as in-house, outsourcing, or hybrid, become the best to use disparate components with a uniform decision-making process. All the findings together prove that the most suitable production strategy depends on the technical and operational needs of the separate parts. The numerical criterion weights obtained in Table 4 directly support this conclusion.

For components such as Jaw Teeth / Grip Segments and Vibroflotation Probe Tip, which are classified as “Complex and Delicate” in Table 6, the results assign higher weights to ‘Scrap Risk (0.23 and 0.22)’ and ‘Customer Satisfaction’ (0.15 and 0.19). These high-priority values indicate that technical precision is crucial. The hybrid production model, therefore, becomes the best setup, achieving the highest scores (0.564 and 0.595) in Figure 2, hence offering a required balance between internal control and external capacity. In the case of components that require high accuracy, e.g., the Hydraulic Manifold Block, where ‘Scrap Risk’ is the highest with 0.29 in Table 4, in-house production is the most appropriate choice with a score of 0.400 in Figure 2. Such a structure allows for maintaining high standards of quality and ensuring the reliability of the system. Conversely, when the components are produced by comparatively standard processes, as in the case of the Electrical Control Cabinet, Table 4 suggests that ‘Total Annual Cost’ (0.23) is the most used criterion, which can be explained by its cost-effectiveness and traditional production needs instead of technical complexity. In this regard, the outsourcing strategy is considered the prevailing one, with a final score of 0.596, thus avoiding capital investment requirements without compromising operational efficiency.

The optimization outcomes show that, due to the limited in-house machine capacity, a fully internal production strategy was not feasible. The distribution of in-house production volumes was mainly based on the joint influence of the AHP preference scores and component-specific processing time, as shown in Figure 3. In particular, the Jaw Teeth/Grip Segments (JTG) was the most in-house-allocated (800 units), as it has the highest AHP score, as well as a comparatively lower machine-time per unit. In the same way, the Jaw Pins & Bushing (JPB), as shown, used a large share of internal capacity (551 units), which is in line with its high strategic priority. As the machine capacity constraint became binding, the remaining available capacity was assigned to the Vibroflotation Probe Tip (VPT). Figure 3 below indicates that the Vibroflotation Probe Tip was only manufactured in-house to a production of 238 units, with the

remaining 762 units being outsourced. The Vibroflotation Probe Tip was not able to get a larger internal allocation within the given capacity constraints due to its relatively high machine-time per unit requirement. The machine capacity was utilized to the full extent, and this proves that it is the main operation bottleneck in the system. Conversely, the labor capacity constraint was not fully binding, indicating that machine availability is the dominant limiting factor. The deviation term further supported a balanced sourcing structure by avoiding extreme allocation results.

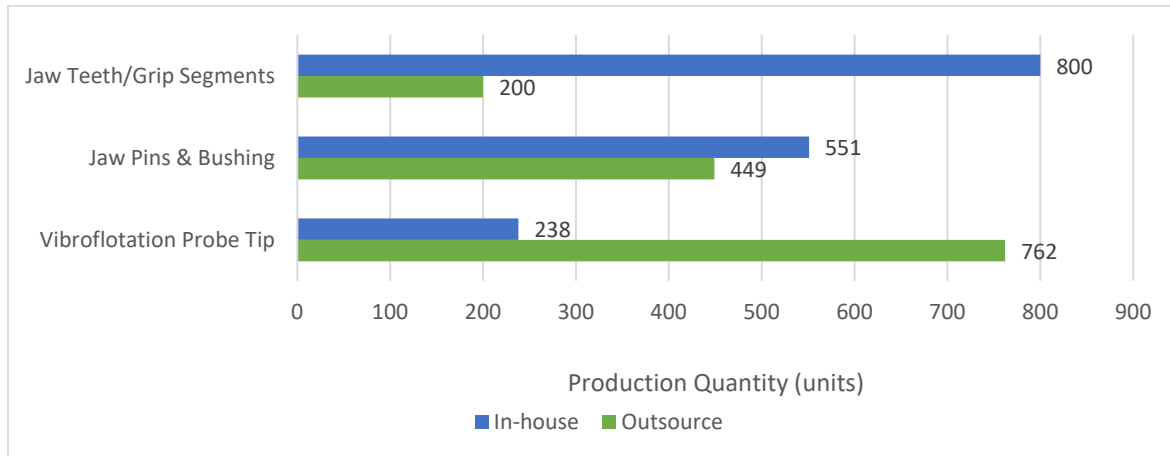


Figure 3. Optimal Production Decision for Hybrid Components

In general, the findings indicate that the model is strategically focused on in-house capacity of components with greater AHP-based significance and higher operational efficiency, and outsourcing is a complementary balancing mechanism in the context of capacity limitation.

### 3.1. Sensitivity Analysis

A sensitivity analysis was performed to determine how the preferences generated by AHP affect the optimization model that is included in the proposed framework. In particular, the objective function parameter  $\lambda$  was changed to different values, and the model was solved again to analyze the effect of cost minimization and AHP-based strategic preferences on the solution.

The model was run with the  $\lambda$  values of 0, 50, 100, 112, 150, and 200, and the results are summarized in Table 7. It can be seen that the production plan is the same in the range of 0 to 111, which means that in this range, the solution is primarily determined by the cost structure and capacity constraints. On the other hand, the solution starts to shift towards the strategic preferences expressed by AHP at 112. At this point, in-house production quantity increases for the JTG component, while the outsourcing allocation increases for the VPT component, respectively. Additionally, the  $\lambda$  parameter values of 150 and 200 were also tested, and it was observed that the production plan continued in the same manner at these values.

Table 7. Sensitivity Analysis Result for Different Values of the AHP Weight Parameter ( $\lambda$ )

| $\lambda$ | VPT<br>Outsource | VPT In-<br>house | JPB<br>Outsource | JPB In-<br>house | JTG<br>Outsource | JTG In-<br>house |
|-----------|------------------|------------------|------------------|------------------|------------------|------------------|
| 0         | 695              | 305              | 450              | 550              | 300              | 700              |
| 50        | 695              | 305              | 450              | 550              | 300              | 700              |
| 100       | 695              | 305              | 450              | 550              | 300              | 700              |
| 112       | 762              | 238              | 449              | 551              | 200              | 800              |
| 150       | 762              | 238              | 449              | 551              | 200              | 800              |
| 200       | 762              | 238              | 449              | 551              | 200              | 800              |

These results indicate that the given model can provide a strong solution to moderate changes in  $\lambda$ , whereas the AHP-based strategic preferences have a visible impact on production choices only after a certain threshold.

#### 4. Conclusion

In this study, rather than the conventional decision processes that are based on cost, an integrated model has been established in the framework of make-or-buy decision-making and is used to decide on the procurement strategies of the spare parts and components of the pile-driving machines. This model takes into consideration multidimensional criteria, including quality, flexibility, and operational risks and constraints by integrating priority scores obtained using AHP into a mathematical optimization model. The penalty coefficients of the hybrid production candidates were incorporated into the model as AHP scores, which allowed the strategic alignment, not just the cost minimization. Consequently, the in-house production capacity was prioritized towards the production of those components that had a greater AHP-based significance, especially the JTG, while lower-priority components such as the VPT were partially outsourced due to the binding capacity constraints. The results indicate that the model can be used to balance economic efficiency, strategic priorities, and operational feasibility under the circumstances of limited machine capacity (2160 hours). Instead of a strictly in-house or strictly outsourcing policy, the offered strategy creates a managed hybrid sourcing system, with the distribution of production volumes being balanced. This validates the usefulness of the combined AHP-MIP model in assisting in making transparent, data-driven, and strategically consistent procurement decisions. This model can be extended in future research to include criteria and constraints like demand uncertainties, logistical costs, or sustainability indices- e.g., carbon emissions- or stochastic capacity constraints.

#### References

- Chen, C.-H., "A novel multi-criteria decision-making model for building material supplier selection based on entropy-AHP weighted TOPSIS," *Entropy*, vol. 22, no. 2, 259, 2020, <https://doi.org/10.3390/e22020259>.
- Kiltila, L. G., Duc, E., Durieux, S. and Taddese, G. A., "An integrated fuzzy AHP-fuzzy TOPSIS approach for multi-criteria decision-making framework in sustainable manufacturing process selection," *The International Journal of Advanced Manufacturing Technology*, vol. 142, pp. 559–583, 2026, <https://doi.org/10.1007/s00170-025-16881-1>.
- Nazir, S., Khan, H. H. and Ahmed, W., "Technological change and decision of make-or-buy in developing economy," *Journal of Managerial Sciences*, vol. 16, no. 1, pp. 130–146, 2022.
- Ortalli, T., Di Martino, A., Longo, M. and Zaninelli, D., "Make-or-buy policy decision in maintenance planning for mobility: A multi-criteria approach," *Logistics*, vol. 8, no. 2, 2024, <https://doi.org/10.3390/logistics8020055>.
- Quispe-Atanacio, W., Moore-Torres, K., Rosales-López, P., Tinoco-Gomez, O. and Salas-Bacalla, J., "A TOPSIS-AHP-based approach for outsourcing service provider selection: A case study in the automotive industry," *Journal of Ecomanagement*, vol. 4, no. 4, pp. 2962–2975, 2026, <https://doi.org/10.62754/joe.v4i4.7076>.
- Rahman, H. U., Raza, M., Afsar, P., Alharbi, A., Ahmad, S. and Alyami, H., "Multi-criteria decision making model for application maintenance offshoring using analytic hierarchy process," *Applied Sciences*, vol. 11, 8550, 2021, <https://doi.org/10.3390/app11188550>.
- Reddy, A., Joseph, N. and Marnewick, A. L., "A make-buy decision framework for new product introduction: An automotive manufacturing perspective," *Proceedings of the 2021 IEEE Technology & Engineering Management Conference – Europe (TEMSCON-EUR)*, 2021, <https://doi.org/10.1109/TEMSCON-EUR52034.2021.9488624>.
- Rosyidi, C. N., Imamah, N. U. F., and Jauhari, W. A., "An optimization model of make or buy decision and quality improvement of components using rebate," *Cogent Engineering*, vol. 7, no. 1, 1767266, 2020, <https://doi.org/10.1080/23311916.2020.1767266>.
- Sarjono, H., Seik, O., Defan, J., and Simamora, B. H., "Analytical Hierarchy Process (AHP) in manufacturing and non-manufacturing industries: A systematic literature review," *Systematic Reviews in Pharmacy*, vol. 11, no. 11, pp. 158–170, 2020.
- Sequeira, M., Hilletoft, P. and Adlemo, A., "AHP-based support tools for initial screening of manufacturing reshoring decisions," *Journal of Global Operations and Strategic Sourcing*, vol. 14, no. 3, pp. 502–524, 2021, <https://doi.org/10.1108/JGOSS-07-2020-0037>.
- Sequeira, M., Adlemo, A. and Hilletoft, P., "A hybrid fuzzy-AHP-TOPSIS model for evaluation of manufacturing relocation decisions," *Operations Management Research*, vol. 15, 2022, <https://doi.org/10.1007/s12063-022-00284-6>.
- Sharma, J., Arora, M., Alsharef, A. and Sonia, "An illustrative study on multi-criteria decision making approach: Analytical Hierarchy Process," *Proceedings of the 2022 2nd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE)*, 2022, <https://doi.org/10.1109/ICACITE53722.2022.9823864>.
- Taş, Ü., "Intuitionistic fuzzy TOPSIS approach for maintenance strategy selection in production," *Journal of Engineering Sciences and Design*, vol. 13, no. 3, pp. 1001–1012, 2025, <https://doi.org/10.21923/jesd.1739911>.

- Tanwar, J., Vaish, A. K. and Rao, N. V. M., “Mathematical modeling of asset liability management in banks using goal programming and AHP,” *Indian Journal of Finance and Banking*, vol. 4, no. 4, 2020.
- van de Water, H. and van Peet, H. P., “A decision support model based on the Analytic Hierarchy Process for the make-or-buy decision in manufacturing,” *Journal of Purchasing & Supply Management*, vol. 12, pp. 258–271, 2006, <https://doi.org/10.1016/j.pursup.2007.01.003>.
- Zahedirad, M., Khalili-Damghani, K., Ghezavati, V. and Rashidi Komijan, A., “A multi-objective multi-period mathematical programming model for integrated project portfolio optimization and contractor selection,” *MethodsX*, vol. 15, 103522, 2025, <https://doi.org/10.1016/j.mex.2025.103522>.

## **Biographies**

**Bilge Öztürk** is a senior student of the Industrial Engineering major at Çankaya University in Ankara, Turkey. She is presently undertaking a graduation project that focuses on the optimization of shuttle routing by using mixed-integer programming models. Her academic activities include operations research, mathematical modeling, multi-criteria decision-making, optimization, and production planning. She has done coursework-based research in linear programming, network models, facility planning, and decision analysis during her undergraduate studies. She has also gained internship experience in production planning, logistics, and quality control in the manufacturing and automobile industries. Her current research project is the incorporation of the Analytic Hierarchy Process (AHP) into mathematical programming models to ease the make-or-buy strategic decision-making process. She is specifically interested in the methodologies of data-driven and optimization-based decision support.

**Syed Shah Sultan Mohiuddin Qadri** is an Assistant Professor in the Department of Industrial Engineering at Çankaya University, Ankara, Turkey. He holds a Ph.D. in Industrial Engineering from Yaşar University, Izmir, Turkey. Dr. Qadri earned his BS and MS degrees in Applied Mathematics from the University of Karachi and NED University of Engineering & Technology, Karachi, Pakistan, in 2010 and 2013, respectively. He has worked as a researcher on a TÜBİTAK-funded project, and his research interests include simulation optimization, intelligent transportation systems, heuristic optimization, and traffic modeling. Dr. Qadri is dedicated to advancing optimization techniques for solving complex real-world problems.

**Şevval Ertan** is a senior student of Industrial Engineering at Çankaya University in Ankara, Turkey. She is in the process of creating a mixed-integer programming formulation of optimization of shuttle routing as her graduation project. Her areas of research are operations research, optimization, multi-criteria decision-making, and production planning. She has acquired internship experience in the manufacturing and automotive industries in production planning, logistics, and quality control. Her scholarly literature emphasizes the combination of the Analytic Hierarchy Process (AHP) and mathematical programming to aid make-or-buy strategic decisions.