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# The model selection of propeller turbine construction using Analytical Hierarchy Process (AHP)

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***Abstract***
*This study aimed to develop an innovative propeller turbine design to facilitate easy manufacturing and maintenance processes, leading to a reduction in costs. Furthermore, the Analytical Hierarchy Process (AHP) method was employed to identify the most optimal model and design for the propeller turbine. Problem-solving within the AHP framework was guided by three fundamental principles, namely decomposition, Comparative Judgment, and Logical Consistency. The procedure included problem decomposition, assessment/ weighting to compare elements, matrix preparation and consistency testing, setting priorities for each hierarchy, priority synthesis, and decision-making. To establish a benchmark, three types of propeller turbines currently available in the market served as references. Meanwhile, the selection criteria for the model were based on several factors, including power factor, time efficiency, ease of manufacture, as well as production and maintenance costs. Considering the criteria, modifications were made to these reference models, resulting in the development of alternatives, denoted as A, B, and C. The results showed that alternative type A as the most suitable choice for further development. Therefore, this particular design was granted foremost priority to develop a low-head generator that possessed ease of manufacturing and surpassed alternative models in terms of feasibility.*

***Keywords:***
*AHP;*
*Modelling;*
*Propeller;*
*Turbine;*

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## INTRODUCTION

Hydrokinetic resources remain an untapped energy source with an estimated annual potential of approximately 120 TWh [1][2]. Numerous regions in Indonesia still face challenges in accessing electricity, particularly due to their remote locations. One potential solution to address this issue involves harnessing the available energy sources surrounding residential areas, such as water [3]. In rural areas, there is a significant abundance of low-head and low-discharge water energy sources. To effectively utilize these sources, it is ideal to employ a generator system that uses a propeller-type turbine [4]. However, propeller turbines are expensive and complex to manufacture compared to other types suitable for low-head applications, such as cross-flow turbines. The primary manufacturing challenges associated with propeller turbines are related to the production of turbine housings and blades [5]. Consequently, this study aims to simplify the design of the turbine housing and blades to facilitate easier manufacturing processes.

For two decades, different studies imparted comprehensive instruction in core MBA management science, specifically in the areas of decision-making and modeling. In particular, a module dedicated to Analytical Hierarchy Process (AHP) has been integrated into the curriculum and also used to as evaluation tool [6]. The feedback received from students regarding the application of this material in their professional and academic pursuits showed that the pedagogical approach is indeed ideal for teaching the method in operations research (OR). Furthermore, AHP has garnered widespread adoption among the analytical community since its inception [7].

In this study, the method for selecting the simple turbine propeller design uses AHP which is a functional hierarchy with the main input being human perception. This method was developed by Prof. Thomas Lorie Saaty from the Wharton Business School in the early 1980s and was used to find a ranking or order of priority from various alternatives in solving a problem [8][9].

AHP can be used for various applications such as Strategic Planning, Resource allocation, and Resource selection [10]. The application has predominantly been observed in the realms of engineering, as well as personal and social categories, in terms of its wide-ranging applicability [11]. This observation can prove valuable to evaluate the suitability of employing AHP in specific areas of interest. Meanwhile, the decision-making scenarios where AHP can be effectively employed encompass a variety of contexts, such as follows [12].

1. Choice - selection of one alternative from a given set involving several decision criteria.
2. Ranking - placing a set of alternatives in order from least desirable.
3. Priority - determine the relative merits of members of a set of alternatives, as opposed to choosing one or only their ranking.
4. Resource allocation - Dividing resources among a set of alternatives.
5. Benchmarking - Comparing processes in their own organization's best processes with others.
6. Quality management – Addressing the multidimensional aspects of quality and quality improvement.
7. Conflict resolution - Resolving disputes between parties.

## MATERIAL AND METHODS

### AHP Procedure

In solving problems with AHP, several principles must be understood [16, 17, 18], namely:

1. Create a hierarchy; Complex systems can be understood by breaking them down into several supporting elements.
2. Assessment of criteria and alternatives by pairwise comparisons. According to Saaty (1988), for various issues, a scale of 1 to 9 is the best scale for expressing opinions. The value of the importance level is shown in the Table 1 [19, 20, 21].
3. Define the rank based on the criteria in in Table 2 [22].
3. Set priorities; For each criterion and alternative, it is necessary to conduct a pairwise comparison. Furthermore, weights and priorities are calculated by matrix or solving equations.
4. Consistency; Consistency has 2 (two) meanings. First, similar objects are grouped according to uniformity and relevance. Second, the level of relationship between objects is based on certain criteria.

Table 1. Pairwise Comparison Rating Scale [13, 14, 15]

| **Importance** | **Definition** | **Remarks** |
|---|---|---|
| **1** | Equal Importance | Both elements have the same effect |
| **3** | Weak importance of one over | Experience and judgment strongly favor one element compared to its pair |
| **5** | Essential or strong importance | One element is more important than the other |
| **7** | Demonstrated importance | One element is clearly more important than the other elements |
| **9** | Extreme importance | One element is absolutely more important than the other elements |
| **2,4,6,8** | Intermediate values between the two adjacent judgments | Values between two adjacent judgment values |
| **Reciprocal** | Opposite | If element *i* has one of the numbers above when compared to element j, then j has the opposite when compared to element *i* |

Table 2. Ranking criteria

| **Intensity / Rank** | **Criteria** |
|---|---|
| 1 | Both elements are equally important |
| 3 | One element is less important than the other other |
| 5 | One element is more important than the other elements |
| 7 | One element is more important than the other elements |
| 9 | One element is more important than the other elements |
| 2, 4, 6, 8 | The values between the two considerations are close together |

5. Measure consistency; In making decisions, it is important to know the level of consistency. This is because decisions are not made based on considerations with low consistency and the steps include [23][24]:
   - Multiply each value in the first column by the priority of the first element.
   - Total each row; the result of the sum of the rows is divided by the relevant relative priority element.
   - Add up the quotient above with the number of elements present, and the result is known as λ max.
6. Calculate the Consistency Index (CI) [25] with (1).

$$CI = (\lambda max - n) / n \tag{1}$$

7. Calculate the Consistency Ratio by (2).

$$CR = CI / IR \tag{2}$$

Where:
CR = *Consistency Ratio*
CI = *Consistency Index*
IR = *Random Consistency Index*

The Random Consistency Index (IR) is listed in Table 3.

8. Check the consistency of the hierarchy.

The data judgment assessment must be corrected when the value is more than 10%. However, when the Consistency Ratio (CI/IR) is 0.1, the calculation results can be declared correct refer to the values listed in Table 4 [26].

Table 3. IR values

| Matrix size | IR Value |
|---|---|
| 1, 2 | 0.00 |
| 3 | 0.58 |
| 4 | 1.90 |
| 5 | 1.12 |
| 6 | 1.24 |
| 7 | 1.32 |
| 8 | 1.41 |
| 9 | 1.45 |
| 10 | 1.49 |
| 11 | 1.51 |
| 12 | 1.48 |
| 13 | 1.56 |
| 14 | 1.57 |
| 15 | 1.59 |

Table 4. Random index values

| **n** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
|---|---|---|---|---|---|---|---|---|
| **R** | 0 | 0 | 0.5 | 0.9 | 1.1 | 1.2 | 1.3 | 1.4 |
| **n** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | |
| **RI** | 1.45 | 1.49 | 1.51 | 1.53 | 1.56 | 1.57 | 1.58 | |

## Method

This study was conducted through several stages, starting from searching related literature, conceptual design, design selection, and analysis until concluding, as shown in Figure 1. The research flowchart is a technical analysis for translating the research aspects raised in a concise, clear and logical manner.

Functionally, flowcharts describe the sequence of processes and help the reader understand well the relationship between object one to another.

## Propeller Turbine for Reference

To obtain an alternative model for simplifying the turbine housing and turbine blades to facilitate manufacturing, it is imperative to establish multiple turbines as points of reference. There are three types of propeller turbines used as a reference: the horizontal (type A), vertical (type B), and turbo tabular turbines (type C). The modifications developed from these three types then called alternative models.

Turbine type A, as presented in Figure 2, will be modified to obtain new alternative with the modification consideration in Table 5. The tubular turbine is characterized by a straight flow passage, large flow, high efficiency, and compact structure, so it has obvious advantages in the development of low-head hydraulic resources. The special structure of the tubular turbine makes its operation performance different from other conventional units, particularly severe vibration, which has become an important factor limiting the safe operation of ultralow-head tubular turbines.

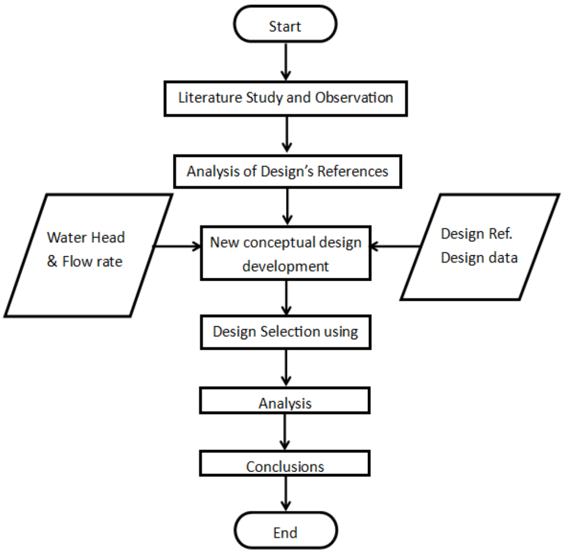

Figure 1. Study flowchart

Table 5. Modifications to be Developed from Type A Turbine

| No | Developed modifications | Modifications | Drawback |
|---|---|---|---|
| 1 | Incoming fluid flow direction | The fluid flow entering from the side is changed to from the front (left) | Inflow from the side will cause losses by the turns and the turbine shaft |
| 2 | Elbow Position | Elbow from the horizontal direction is changed to be vertical | The fluid flowing through the horizontal elbow takes longer compared to vertical |
| 3 | Draft tube | The draft tube from the left is changed to be under the elbow which is positioned vertically. The inlet diameter is made the same as the inlet draft tube. | The inlet is much larger than the inlet of the draft tube which will cause flow restriction on a spoon. |

Table 6. Modifications to be Developed from Type B Turbine

| No | Developed modifications | Modifications | Drawback |
|---|---|---|---|
| 1 | Axis position | From vertical to horizontal | The weight of the dynamo will increase the load on the shaft |
| 2 | Elbow | The elbow with a smaller inlet diameter is replaced with an elbow that has the same inlet and outlet diameters | Will cause pressure loss |
| 3 | Shaft | Previously the position of the blade approaching the draft tube was changed to the position before the flow entered the elbow | Will cause a lot of turbulence. |

Turbine type B, as shown in Figure 3, will be developed further to obtain new alternative with the modification consideration shows in Table 6. Tubular turbine and Bulb turbine is suitable for heads from 2m to 20m. Its feature is that the water flow is axial throughout the passage from the inlet to the outlet, so that the passage is a straight conduit essentially. The tubular turbine is characterized by good characteristic of water flow and high efficiency etc.

Lastly, as presented in Figure 4, turbine type C will be reconstructed further to obtain new alternative with the modification consideration shows in Table 7. This is a domestic production turbine produced by Cihanjuang Core Techniques located on Jl. Cihanjuang No. 204, Cibabat, Kec. North Cimahi, City of Cimahi, West Java 40513, Indonesia.

Figure 2. Horizontal Tubular Turbine [27, 28, 29]

Figure 3. Vertical Tubular Turbine [21, 27, 29]

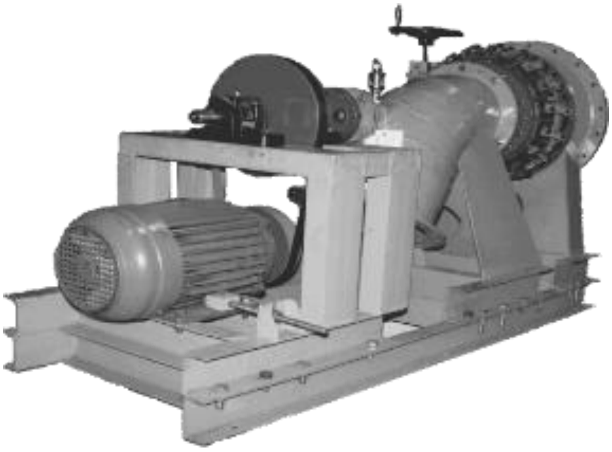

Figure 4. Horizontal Tubular Turbine Turbo Model [1, 27, 30]

Table 7. Modifications to be Developed for the Type C Turbine

| No | Developed modifications | Modifications | Drawback |
|---|---|---|---|
| 1. | Transmission | Direct transmission using coupling flange | Cause power loss due to friction |
| 2 | Elbow | The incoming and outgoing diameter elbows are made the same and replaced with elbows from the casting process | The friction as the flow passes over the elbow will be higher |
| 3 | Blade | Changeable blade types are replaced with fixed blades | The tilted blade is complicated to manufacture |

## Alternative Models

To obtain a new form, a modification of the reference propeller turbines is carried out. Three new ideas emerged from the modification of the reference turbines as follows:

The alternative A was designed by making the inlet diameter identical to the elbow diameter by deploying a clutch as the transmission system (Figure 5). Draft tube is made conical and placed in a vertical position which is connected to the 45° elbow connected with a flange. The propeller is placed just before the entrance of the elbow with 4 blades. The supporting frame is made larger to protect all components using a U-shape steel profile.

The alternative B (Figure 6) was designed by making the inlet diameter larger than the elbow diameter and using a clutch as the transmission system (Figure 5). Draft tube is made conical and placed in a vertical position which is connected to the 45° elbow connected with a flange. The 4 blades propeller is placed just before the entrance of the elbow where the diameter reduced. The supporting frame is made shorter where inlet tube is located protruding out of the frame.

The alternative C modified by making the inlet diameter identical to the elbow diameter by deploying a clutch as the transmission system (Figure 7). Draft tube is made conical and placed in a vertical position which is connected to the 45° elbow connected with a flange. The 4 blades propeller is placed at the entrance of the inlet, therefore a long propeller supporting shaft is required. The supporting frame is made shorter where inlet tube is located protruding out of the frame.

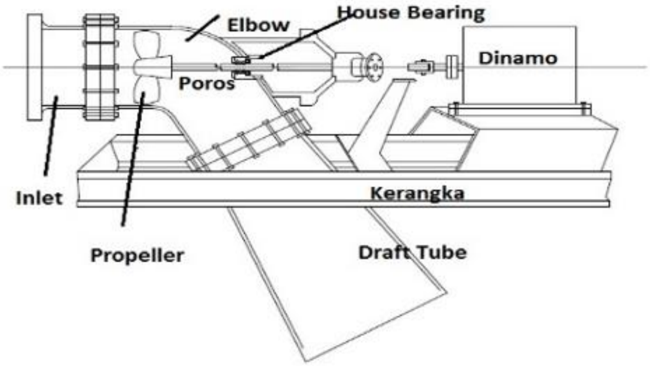

Figure 5. Design for Alternatives “A”

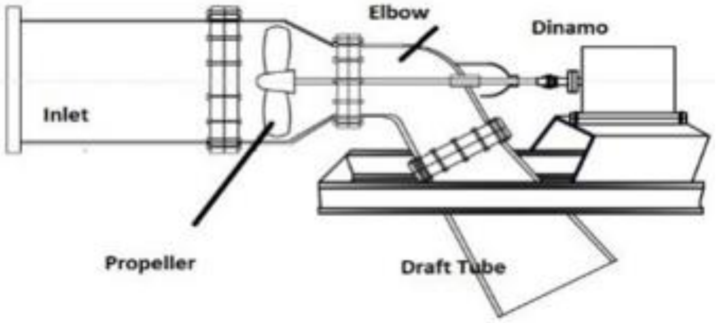

Figure 6. Design for Alternatives “B”

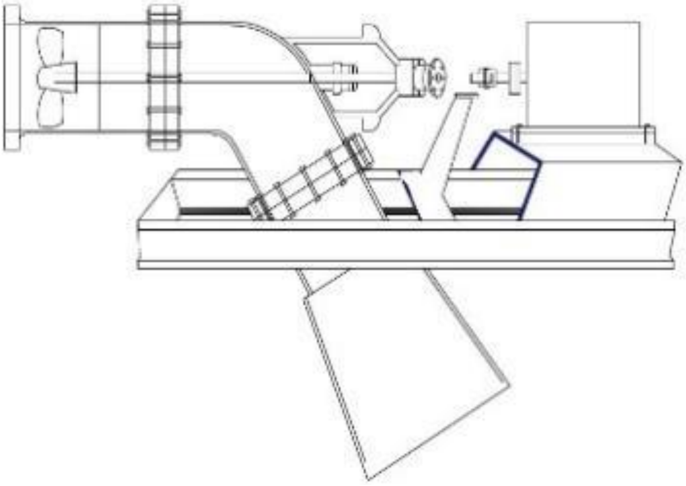

Figure 7. Design for Alternatives “C”

## RESULTS AND DISCUSSION

There are five aspects/ criteria need to be considered when selecting a turbine design, which are:

1) Efficiency,
2) Power generated,
3) Production costs,
4) Time and Ease of Production
5) Treatment / Maintenance.

The selection in this study uses the AHP method and the hierarchical structure of the process as shown in Figure 8. Comparison between the criteria components is used to choose best developed alternative design using this AHP method [31, 32, 33, 34]. Pairwise comparison matrices were carried out for comparative assessments between one criterion and another, such as efficiency, power produced, production costs, production time and ease of maintenance.

Table 8 explains that the power generated for efficiency is given a weight of 3 because the power generated is slightly more important than the efficiency, production costs for efficiency is weighted 5 because production costs is more important to consider than efficiency. The ease of assembly is weighted 5 because this criterion becomes more important as this turbine designed to be used in rural areas where most users are technologically illiterate.

It is necessary to determine the weight of each criterion as shown in the Table 9. This normalize pairwise matrix table is to calculated the weight of the criteria by the average of all the elements in the row, by adding all these elements and dividing by the number of criteria which will give the weight of the criterion.

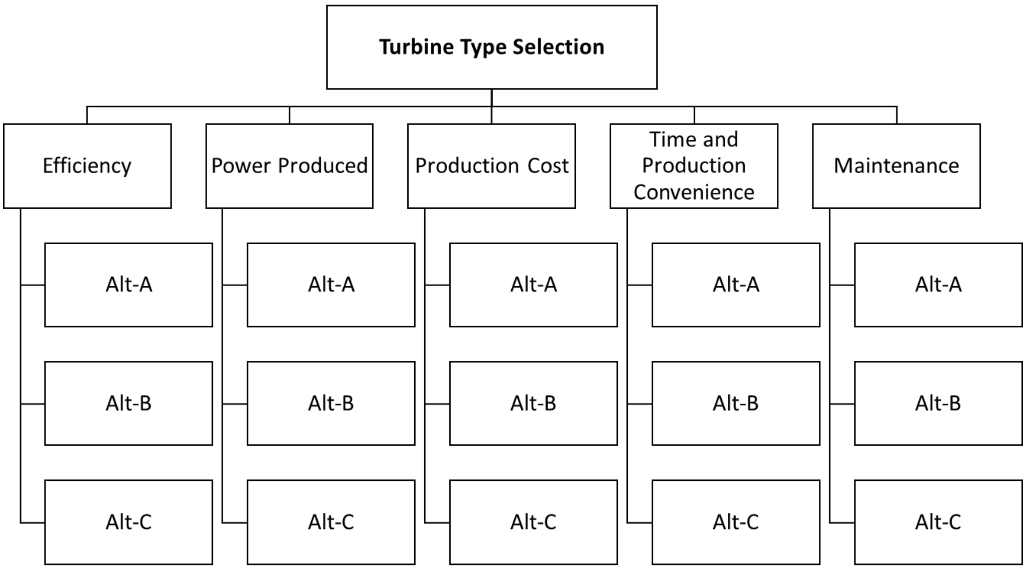

Figure 8. Alternative Turbine Lay Out

Table 8. Paired Criteria Comparison Score

| Criteria | Efficiency (1) | Power (2) | Cost (3) | Time & ease (4) | Maintenance (5) | Eigen Value | Priority Weighting | Validation |
|---|---|---|---|---|---|---|---|---|
| **Efficiency (1)** | 1.000 | 3.000 | 5.000 | 4.000 | 3.000 | 2.825 | 0.434 | 2.117 |
| **Power (2)** | 0.333 | 1.000 | 2.000 | 5.000 | 3.000 | 1.585 | 0.244 | 5.033 |
| **Cost (3)** | 0.200 | 0.500 | 1.000 | 5.000 | 5.000 | 1.201 | 0.185 | 8.400 |
| **Time & ease (4)** | 0.250 | 0.200 | 0.200 | 1.000 | 6.000 | 0.570 | 0.088 | 15.167 |
| **Maintenance (5)** | 0.333 | 0.333 | 0.200 | 0.167 | 1.000 | 0.326 | 0.050 | 18.000 |
| **TOTAL** | 2.117 | 5.033 | 8.400 | 15.167 | 18 | 6.507 | | |

Table 9. Weight Validation Determination Matrix

| Criteria | Efficiency (1) | Power (2) | Cost (3) | Time & ease (4) | Maintenance (5) | Synthesis Weighting | Eigen Maximum |
|---|---|---|---|---|---|---|---|
| **Efficiency (1)** | 0.472 | 0.596 | 0.595 | 0.264 | 0.167 | 2.094 | 4.823 |
| **Power (2)** | 0.157 | 0.199 | 0.238 | 0.330 | 0.167 | 1.091 | 4.478 |
| **Cost (3)** | 0.094 | 0.099 | 0.119 | 0.330 | 0.278 | 0.920 | 4.986 |
| **Time & ease (4)** | 0.118 | 0.040 | 0.024 | 0.066 | 0.333 | 0.581 | 6.636 |
| **Maintenance (5)** | 0.157 | 0.066 | 0.024 | 0.011 | 0.056 | 0.314 | 6.262 |
| **TOTAL** | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 5.000 | 27.184 |
| **CI = (λmax-n)/(n-1) and CR = CI/RI for n= 5, RI =1.12 Because CR < 0,100 then weighting preferences is consistent** | | | | | | (λmax)<br>CI<br>CR | 5.437<br>0.109<br>0.091 |

To determine the weight validation in Table 9, the value of 0.472 is calculated by dividing the efficiency weight (value 1) in Table 8 divided by the total efficiency weight (value 2.117). The same method was carried out for the criteria for power, time and maintenance; therefore, it is found that the CI = 0.109 and CR 0.091 for the ease of production criteria.

Determining the Global Weight of Each Alternative is done by determining the weight of each alternative for each criterion for the alternative turbines Type A, Type B and Type C.

In terms of efficiency, the global weight of alternative Turbine design resulting a value of 0.322 for Type A, 0.285 for Type B and 0.393 for Type C, as listed in Table 10. Type C is confirmed as a design with the highest efficiency.

Based on Table 11 it is determined that Type A with the value of 0.416 resulting the highest global weight for Power Generated. Table 12 shows that alternative type A obtain the highest value of 0.375 for the process time and ease of production. Highest weighting value obtained by alternative type A by 0.418 points which means that this design has lowest production cost as listed in Table 13. Table 14 shows the maintenance cost weighting matrix. Type B was decided as the alternative design with the lowest maintenance cost for obtaining the highest value of 0.394

Table 10. Efficiency Weighting Matrix

| **Efficiency** | **Turbine Type A** | **Turbine Type B** | **Turbine Type C** | **Eigen Value** | **Global weight** |
|---|---|---|---|---|---|
| **Type A** | 1.000 | 1.333 | 0.667 | 1.437 | 0.322 |
| **Type B** | 0.750 | 1.000 | 0.333 | 1.274 | 0.285 |
| **Type C** | 1.500 | 3.003 | 1.000 | 1.755 | 0.393 |
| **TOTAL** | 3.250 | 5.336 | 2.000 | 4.466 | 1.000 |

Table 11. The resulting Power Weight Determination Matrix

| **Efficiency** | **Turbine Type A** | **Turbine Type B** | **Turbine Type C** | **Eigen Value** | **Global weight** |
|---|---|---|---|---|---|
| **Type A** | 1.000 | 3.000 | 4.000 | 1.986 | 0.416 |
| **Type B** | 0.333 | 1.000 | 3.000 | 1.622 | 0.340 |
| **Type C** | 0.250 | 0.333 | 1.000 | 1.164 | 0.244 |
| **TOTAL** | 1.583 | 4.333 | 8.000 | 4.772 | 1.000 |

Table 12. Matrix of Determining Process Time Weight and Ease of Production

| **Time & Production Convenience** | **Turbine Type A** | **Turbine Type B** | **Turbine Type C** | **Eigen Value** | **Global weight** |
|---|---|---|---|---|---|
| **Type A** | 1.000 | 5.000 | 3.000 | 2.065 | 0.375 |
| **Type B** | 0.200 | 5.000 | 3.000 | 2.002 | 0.364 |
| **Type C** | 0.333 | 1.667 | 1.000 | 1.437 | 0.261 |
| **TOTAL** | 1.533 | 11.667 | 7.000 | 5.504 | 1.000 |

Table 13. Production Cost Weighting Matrix

| **Production Cost** | **Turbine Type A** | **Turbine Type B** | **Turbine Type C** | **Eigen Value** | **Global weight** |
|---|---|---|---|---|---|
| **Type A** | 1.000 | 6.000 | 3.000 | 2.138 | 0.418 |
| **Type B** | 0.167 | 1.000 | 5.000 | 1.823 | 0.357 |
| **Type C** | 0.333 | 0.200 | 1.000 | 1.151 | 0.225 |
| **TOTAL** | 1.500 | 7.200 | 9.000 | 5.112 | 1.000 |

Table 14. Maintenance Cost Weighting Matrix

| **Maintenance** | **Turbine Type A** | **Turbine Type B** | **Turbine Type C** | **Eigen Value** | **Global weight** |
|---|---|---|---|---|---|
| **Type A** | 1.000 | 1.333 | 3.000 | 1.737 | 0.364 |
| **Type B** | 0.750 | 1.000 | 5.000 | 1.878 | 0.394 |
| **Type C** | 0.333 | 0.200 | 1.000 | 1.151 | 0.242 |
| **TOTAL** | 2.083 | 2.533 | 9.000 | 4.767 | 1.000 |

Table 15. Recap of Weight Calculation results

| **Alternative** | **Efficiency** | **Power produced** | **Time & Production Convenience** | **Production Cost** | **Maintenance** | **Total weight** |
|---|---|---|---|---|---|---|
| | | | **Priority weight** | | | |
| | **0.434** | **0.244** | **0.185** | **0.088** | **0.050** | |
| **Type A** | 0.322 | 0.416 | 0.375 | 0.418 | 0.364 | **0.365** |
| **Type B** | 0.285 | 0.340 | 0.364 | 0.357 | 0.394 | 0.325 |
| **Type C** | 0.393 | 0.244 | 0.261 | 0.225 | 0.242 | 0.310 |

Based on the review of the weight calculation as listed in Table 15, the results have been analyzed concerning the five key aspects considered for turbine design, namely Efficiency, Power generation, Production costs, Time and Ease of Production, and Maintenance. The type C turbine holds the highest weight for work efficiency with a value of 0.393. In terms of power generation, time, and ease of workmanship, the type A turbine holds the highest weight for production costs, with values of 0.416, 0.375, and 0.418, respectively. Moreover, the type C turbine is the best option when it comes to maintenance. In considering the total weight, the type A, B, and C turbines hold values of 0.365, 0.325, and 0.310. The final calculation of the total weight decided that the type A turbine obtained the highest value of 0.365. The type A turbine obtained the best overall criteria even though lower in efficiency and maintenance values. Therefore, this type A is the most feasible option to pursue. The Propeller Turbine has an outstanding reputation for its high specific flow capacity. As a double-regulated turbine it is therefore most suitable for low heads and large flows, but also for variable head and flow conditions. It is ideally suited for sites with heads between 1.5 meters and 15 meters maximum.

## CONCLUSION

The development of turbine blades poses significant challenges, primarily in the areas of housing and manufacturing. Therefore, this study endeavors to address the difficulties by proposing simplified designs for both the turbine housing and blades, to enhance the ease of manufacturing. The turbine housing is streamlined through the utilization of steel pipe materials, while the blades are simplified by eliminating the aerodynamic cross-sections, allowing the use of steel plates instead of casting. To ensure the effectiveness of these simplified designs, further study is required to assess the efficiency of the new cross-sectional shapes, considering both aerodynamic and non-aerodynamic effects. The AHP method has proposed the type A design as the best design to develop further. Additionally, the pursuit of alternative blade designs remains a challenging topic that warrants further development and exploration.

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