Fuzzy Analytic Hierarchy Process Method for Selecting the Best Design Concept of Corn Shelling Machine

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Abstract. The main objective of this research is to choose the best design concept of the corn sheller machine in the early phases of the product development process and the research method used is the Fuzzy Analysis Hierarchy Process method of this paper proposed for the selection of the best concepts. Three alternative design concepts from the corn sheller machine, C1, C2 and C3, have been produced and evaluated to identify the most promising design concepts. The results of this study are the assessment and decisions during the concept evaluation made with respect to a set of criteria that have been established based on customer needs and the intentions of the designer. The selection criteria are ease of use, ease of maintenance, capacity, and security ease of manufacture and cost of manufacture. Through the application of Fuzzy Analytic Hierarchy Process the results show that C3 design concept has the highest total score and is ranked first, C2 design concept is ranked second, and C1 design concept has the lowest rank. According to the results of the C3 design concept was chosen as the best concept of the corn sheller machine.

1. Introduction

Corn, also known as maize, is a grain plant cultivated for food. In Indonesia, corn is the second most important cereal crop after rice [1]. Corn shelling a post-harvest operation is the removal of kernels from the cobs [2]. Traditionally shelling the corn grain is done by hand but it is tedious labour with low productivity [3]. In order to help farmers simplifying their work and increasing their productivity a product development process to develop a corn shelling machine has been carried out. In the early stages of product development, three potentially design concepts of corn shelling machine have been generated and those concepts have to evaluated for selecting the best design concept.

Decisions which are made during concept selection process have a significant impact on the level of success of product. During the evaluation and selection concept stage designers should consider not only the product functionality needed, but also other criteria, such as ease manufacture, ease of maintain, cost. In most design situations, some criterion contradicts each other at the same time. Hence, the evaluation can be defined as a multi-criteria decision-making problem under uncertainty owing to multiple, mostly conflicting criteria and imprecise information in the early design stage. [4]

Fuzzy Analytic Hierarchy Process (Fuzzy AHP) is the combination of Analytic Hierarchy Process (AHP) and fuzzy set theory. The Analytic Hierarchy Process (AHP) was firstly proposed by Thomas Saaty has been widely used to solve multiple criteria decision-making problems. The Analytic Hierarchy Process (AHP) is a Multi Criteria Decision Making approach in which factors that are important for decision are arranged in a hierarchic structure, descending from an overall goal to criteria, sub criteria and alternatives in successive levels [5]. In order to achieve the goal, pairwise comparisons of all criteria...
are carried out to determine the relative importance of each criterion. Then pairwise comparisons are conducted between all alternatives separately for each criterion. Based on these comparisons an overall selection is made. However, due to vagueness and uncertainty in the decision maker’s judgment, a crisp, pair-wise comparison with conventional AHP may be unable to accurately capture the decision maker’s judgment. Therefore, fuzzy logic is introduced into the pairwise comparison in the AHP to compensate for this deficiency in the conventional AHP [6]. Fuzzy AHP can be used to reduce the uncertainty in conventional AHP and to give more accurate description of the decision-making process [7]. Similar to AHP, Fuzzy AHP has also been widely applied to concept design evaluation problems. For instance, Fuzzy AHP was used for selecting alternatives in the conceptual design phase [8]. Fuzzy AHP was also applied to evaluation and selection of new product [9], green product [10], notebook computers [11], luggage bag [12].

In this paper a structured concept selection methodology based on Fuzzy AHP is proposed to evaluate and to select the best concept of a corn shelling machine in the early design phase. Using the proposed method, three alternative concepts of corn shelling are evaluated with respect to a set of selection criteria which has been defined based on customer needs and designers’ intentions.

2. Methods

In Fuzzy AHP the linguistic variables were used for the judgment of comparison values are expressed into fuzzy numbers. Linguistic variables are variable whose values are not numbers but words or sentences from a natural language. A linguistic variable is generally decomposed into a set of linguistic terms. Fuzzy AHP comes into implementation in order to overcome the compensatory approach and the inability of the AHP in handling linguistic variables. In Fuzzy AHP linguistic terms (e.g. high, very high) or a fuzzy number can be assigned instead of providing a precise numerical value. Fuzzy numbers are a fuzzy subset of real numbers, representing the expansion of the idea of the confidence interval [13]. In this paper triangular fuzzy numbers adopt to characterize the membership function due to computational simplicity. Triangular fuzzy numbers can be denoted by \( \tilde{A} = (l, m, u) \), where \( l, m \) and \( u \) stand for lower, middle and upper value, respectively, of the fuzzy number \( \tilde{A} \).

A fuzzy number \( \tilde{A} \) on \( R \) would be triangular fuzzy numbers if its membership function \( \mu_{\tilde{A}}(x): R \to [0,1] \) is equal to: [13]

\[
\mu_{\tilde{A}}(x) = \begin{cases} 
(x - l)/(m - l), & l \leq x \leq m \\
(u - x)/(u - m), & m \leq x \leq u \\
0, & x < l, x > u 
\end{cases}
\] (1)

2.1. The steps of Fuzzy AHP

The steps of Fuzzy AHP to select design concept are as follows:

*Step 1: Define a set of design concepts*

Design concepts are developed during the early stages of product development process. The designers generated a set of design concepts that need to be evaluated in order to select the best concept for further development.

*Step 2: Define selection criteria*

The designers need to define a set of selection criteria to differentiate among the concepts. The selection criteria are chosen based on the customer needs the designers has identified as well as on other needs such as manufacturing cost.

*Step 3: Construct hierarchy structure*

At this step the decision problem is decomposed into a hierarchy. The top level of the hierarchy represents the overall goal of the problem which is to choose the best design concept, the intermediate levels represent the selection criteria affecting the decision, and the bottom level represents the alternatives of design concept.

*Step 4: Identifying linguistic variables*

The linguistic term and linguistic variable are expressed using triangular membership function. The linguistic terms and corresponding triangular fuzzy numbers are given in Table 1 [14].
Table 1 Linguistic terms and triangular fuzzy number

| Linguistic terms          | Triangular fuzzy numbers | Inverse           |
|---------------------------|--------------------------|-------------------|
| Equally preferred         | (1,1,1)                  | (1,1,1)           |
| Moderately preferred      | (2,3,4)                  | (1/4, 1/3,1/2)    |
| Strongly preferred        | (4,5,6)                  | (1/6,1/5,1/4)     |
| Very strongly preferred   | (6,7,8)                  | (1/8,1/7,1/6)     |
| Absolutely preferred      | (9,9,9)                  | (1/9,1/9,1/9)     |
| Intermediate values       | (1,2,3)                  | (1/3,1/2,1/1)     |
|                           | (3,4,5)                  | (1/5,1/4,1/3)     |
|                           | (5,6,7)                  | (1/7,1/6,1/5)     |
|                           | (7,8,9)                  | (1/9,1/8,1/7)     |

Step 5: Compare the selection criteria or alternative concepts
At this stage decision maker compares the selection criteria or alternative concepts using Table 1.

Step 6: Construct fuzzy pairwise comparison matrix
Pairwise comparison matrix $\tilde{A}$ is shown in equation (2), where $\tilde{a}_{ij}$ is a triangular fuzzy number, $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ and $\tilde{a}_{ji} = 1/\tilde{a}_{ij}$. $\tilde{a}_{ij}$ denotes the decision maker preference of $i^{th}$ criterion over $j^{th}$ criterion via triangular fuzzy numbers.

$$\tilde{A} = \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \ldots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \ldots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \ldots & \tilde{a}_{nn} \end{bmatrix}$$ (2)

Step 7: Calculate fuzzy weight of criteria
Fuzzy weight matrix is calculated by Buckley’s geometric mean method [15]. The geometric mean of fuzzy can be calculated by using equation 3:

$$\bar{r}_i = \left( \prod_{j=1}^{n} \tilde{a}_{ij} \right)^{1/n}, \text{ for all } i$$ (3)

Where $\bar{r}_i$ is the geometric mean of fuzzy comparison values of criterion $i$ to each criterion.

Fuzzy weight $\tilde{w}_i$ of the $i^{th}$ criterion indicated by a triangular fuzzy number is as follows:

$$\tilde{w}_i = \bar{r}_i \otimes (\bar{r}_1 \oplus \bar{r}_2 \oplus \ldots \oplus \bar{r}_n)^{-1}$$ (4)

Where $l\tilde{w}_i, m\tilde{w}_i, u\tilde{w}_i$ stands for the lower, middle, and upper values of the fuzzy weight of the $i^{th}$ criterion.

Step 8: Defuzzification
Since $\tilde{w}_i$ are still fuzzy numbers, these fuzzy weights are defuzzified into non fuzzy numbers by using the center area method as follows:

$$w_i = \frac{l\tilde{w}_i + m\tilde{w}_i + u\tilde{w}_i}{3}$$ (5)

Step 9: Normalization of non-fuzzy number
The non-fuzzy weights $w_i$ have to normalized by using equations 6:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$$ (6)

Where $W_i$ represents normalized weight of the $i^{th}$ criterion.
Step 10: Consistency check of the comparison matrix
To check the consistency of the comparison matrix, the consistency rate (CR) have to be calculated. The CR is defined as a ratio between the consistency of a consistency index (CI) and the consistency of a random consistency index (RI). The Consistency Ratio (CR) is calculating by using the formula as in equation 7 and the value should not exceed 0.1 [15]. The RI values for different number of criteria is shown in the Table 2.

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

Where: \(\lambda_{max}\) is eigen vector and \(n\) is the number of criteria

| n  | 1 | 2 | 3  | 4 | 5 | 6 | 7 | 8  | 9 | 10 | 11 | 12 |
|----|---|---|----|---|---|---|---|----|---|----|----|----|
| RI | 0 | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 | 1.58 |

Step 11: Calculate the weight of alternative concepts
At this step the three alternative concepts are compared among others with respect to each selection criteria. To find the weight of alternative concepts, similar procedures to that described in step 5 to step 10 are performed.

Step 12: Calculate the total score and the rank of alternative concepts
The total score for each concept is calculated by using equation 9

\[
S_j = \sum_{i=1}^{n} WC_{ij} W_i
\]

Where: \(WC_{ij}\) = weight of concept \(j\) for the \(i\)th criterion, \(W_i\) = weight for \(i\)th criterion, \(n\) = number of criteria, \(S_j\) = total score for concept \(j\).

Finally, each concept is given a rank corresponding to its total score.

3. Result and Discussion
In this paper, Fuzzy AHP has been applied to evaluate and to select the best concept of corn shelling machine. After doing several steps in product development process, three design concepts of a corn shelling have been generated, namely Concept 1 (C1), Concept 2 (C2) and Concept 3 (C3) (Figures 1-3).

![Figure 1. Concept 1](image-url)
Concept 1 uses an AC motor that converts electrical energy into rotational mechanical energy. The rotation and torque from the motor shaft are transmitted via pulley and belt to rotate shelling grates which are made of rubber and to drive the chains which are placed inside the horizontal tube. The kernels are removed from the cobs due to the rubbing force of the shelling grate. The kernels fall out through a wire screen into a container placed underneath the machine. The corn cob is then ejected out, since it cannot pass through the wire screen. The Concept 1 can be seen in Figure 1.

Concept 2 as shown in Figure 2 is powered by motor AC. The corn cob is hand fed into a hole of rotating horizontal tube which have rubbing grates made of rubber inside the tube for shelling cob. The kernels fall out through a vertical cone into a container placed underneath the machine. The rotation of the sheller is powered by motor AC.

In concept 3 the kernels are removed from the cob by a combination of impact, rubbing and centrifugal action as the corn passes the rotating disk-shaped rubber grater. The kernels flow the cylindrical drum before fall out into container. The Concept 3 can be seen in Figure 3.

To differentiate among concepts, six selection criteria have been defined based on customer needs and designers intentions. The selections criteria are ease of use, ease of maintain capacity, safety, and ease of manufacture and cost of manufacture. To decompose the decision problems of choosing the best concept of corn shelling, three levels of hierarchy structure are created as shown in Figure 4.
Decision maker compare the selection criteria by using the linguistic variable and corresponding triangular fuzzy number as is shown in Table 1. After doing constructing pairwise comparison matrix, calculating fuzzy weight of criteria, defuzzifying and normalizing of non-fuzzy number, the weight of each criterion can be found. The level of inconsistency in comparison matrix is acceptable as the value of consistency ratio (CR) is less than 0.1. To find the weight of alternative concepts C1, C2, C3 are compared among others with respect to each selection criteria and the procedures are similar to that described in step 5 to step 10. Finally, the total score and the rank of each concepts can be calculated. The weight of alternative concepts with respect to each criterion, total score and rank of each concept are tabulated as shown in Table 3.

Table 3 Weight, total score and rank of alternative concepts

| Criteria          | Weight of criteria, $W$ | Weight of alternative concepts, $W_C$ | Rank |
|-------------------|-------------------------|---------------------------------------|------|
| Ease of use       | 0.165                   | 0.454 C1                              | 3    |
| Ease of maintain  | 0.058                   | 0.202 C1                              | 3    |
| Capacity          | 0.318                   | 0.474 C1                              | 3    |
| Safety            | 0.118                   | 0.403 C1                              | 3    |
| Ease of manufacture | 0.040                | 0.083 C1                              | 3    |
| Cost of manufacture | 0.301               | 0.083 C1                              | 3    |
| Total score, $S_j$|                         | 0.313 C1                              | 3    |

Table 3 shows that capacity has the highest criteria weight, it means the capacity is the most important requirement for designing of corn shelling machine. The performance of corn shelling machine is influenced by its capacity [1]. Also as seen in Table 3, design concept C3 has the highest total score and is ranked first, design concept C2 is ranked second, and design concept C1 has lowest rank. The Fuzzy AHP as applied to select design concept, therefore, shows that design concept C3 provides the best design concept of corn shelling machine compared with the others. Based on this result the concept C3 may be further developed, prototyped and tested.

4. Conclusion
In this paper, Fuzzy AHP method has been used to evaluate and to select the best design concept of corn shelling machine. Fuzzy AHP can handle the vagueness associated with subjective assignments and comparison in the design concept evaluation stage. The alternative design concepts of corn shelling are evaluated with respect to six selection criteria. The result shows that design concept C3 has the highest total score therefore design concept C3 is selected as the best design concept.
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