

# Selection of Best Method for Pasting of Battery Plate with the Application of Fuzzy AHP

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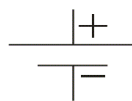
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**ABSTRACT:** This paper presents the Fuzzy Analytical Hierarchy process (FUZZY AHP) as a potential method for estimating the best alternative for pasting of battery plate in a battery manufacturing unit as a case study. A hierarchical structure is constructed for the parameters involved in the pasting alternatives, estimating the priority vectors for the alternatives involved in the pasting process, then estimating the global vector for the alternatives. The alternative which is having the highest global vector is taken as the best alternative.

**KEYWORDS:** Fuzzy AHP, Consistency Index (CI), Consistency Ratio (CR), local vectors, global vectors

## I. INTRODUCTION

A battery is a device that converts chemical energy to electrical energy. The first battery was developed by Alessandro Volta in the year of 1800. In the year 1836, John Frederic Daniell, a British chemist developed the Daniell cell as an improved version of the voltaic cell. From that time until today, the battery has been the most popular source of electricity in many daily life applications.



We often see this symbol in many diagrams of electrical and electronics network. This is the most popularly used symbol for battery. The bigger lines represent positive terminal of the cells and smaller lines represent negative terminal of the cells connected in the battery.

The positive terminal and negative terminal are nothing but positive plate and negative plate. These plates consist of metal grid and chemical paste which gives the positive and negative properties to the plates. Here in this industry, they are using two methods to paste the grids in order to prepare plates for the battery. They are Belt pasting & Orifice pasting.

Chakravorty, (2009) proposed a model for successful implementation of six sigma so that it can reduce the variation or waste from the operation. S. Soni et al., (2013) discussed the quality and productivity improvement in a manufacturing enterprise. This study deals with an application of Six Sigma DMAIC (Define-Measure-Analyze-Improve-Control) methodology in an industry. H.C Hung and M.H. Sung, (2011) explored how a food company in Taiwan can use a systematic and disciplined approach to move towards the goal of Six Sigma quality level. The DMAIC phases were utilized to decrease the defect rate of small custard buns by 70% from the baseline to its entitlement.

The main limitation with this six sigma is that it only considers the measurable aspects of a criterion. But the criteria have both qualitative and quantitative characteristics. One more thing is that, this six sigma technique cannot be

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applicable in finding out the best method among the available. Hence an algorithm that considers both the aspects can be fulfilled with Fuzzy Analytical Hierarchy Process.

Fuzzy AHP is an easy and powerful technique, and is especially suited for problems involving both qualitative and quantitative criteria. The methodology of Fuzzy AHP attempts to analyze the impacts of elements in the lowest levels on the overall objective or focus of a hierarchy. The strength of this approach is that it organizes tangible and intangible factors in a systematic way and provides a structured yet relatively simple solution to the problem.

In this paper, Fuzzy AHP technique is used for the selection of best method for pasting of battery plate. By considering the priorities between criteria and sub-criteria, the local and global vectors are calculated for all the alternatives considered in the case study. The alternative that is having the highest global vector is considered as the best pasting method.

## II. FUZZY ANALYTICAL HIERARCHY PROCESS

The fuzzy AHP is the fuzzy addition of AHP to proficiently handle the fuzziness of the data drawn in the decision making. It is easier to understand and it can be effectively handle both qualitative and quantitative data in the multi-attribute decision making problems. In this approach triangular fuzzy numbers are used for the preferences of one criterion over another and then the pair wise comparison is calculated.

To contract with vagueness of human thought, Zadeh first proposed the fuzzy set theory, which was oriented to the rationality of uncertainty due to ambiguity or vagueness. A major contribution of fuzzy set theory is its ability of representing vague data. The theory also allows mathematical operators and programming to pertain to the fuzzy domain. A fuzzy set is a class of objects with a range of grades of membership. Such a set is characterized by a membership (characteristic) function, which assigns to each object a grade of membership ranging between zero and one. A tilde “~” will be positioned above a symbol if the symbol represents a fuzzy set.

Though the purpose of AHP is to capture the expert’s knowledge, the conventional AHP still cannot reflect the human thinking style. Therefore, fuzzy AHP, a fuzzy extension of AHP, was developed to solve the hierarchical fuzzy problems. In the fuzzy-AHP procedure; the pairwise comparisons in the judgment matrix are fuzzy numbers that are modified by the designer’s emphasis.

Fuzzy numbers and their intensity of importance, definition and membership function are shown below in Table 1.

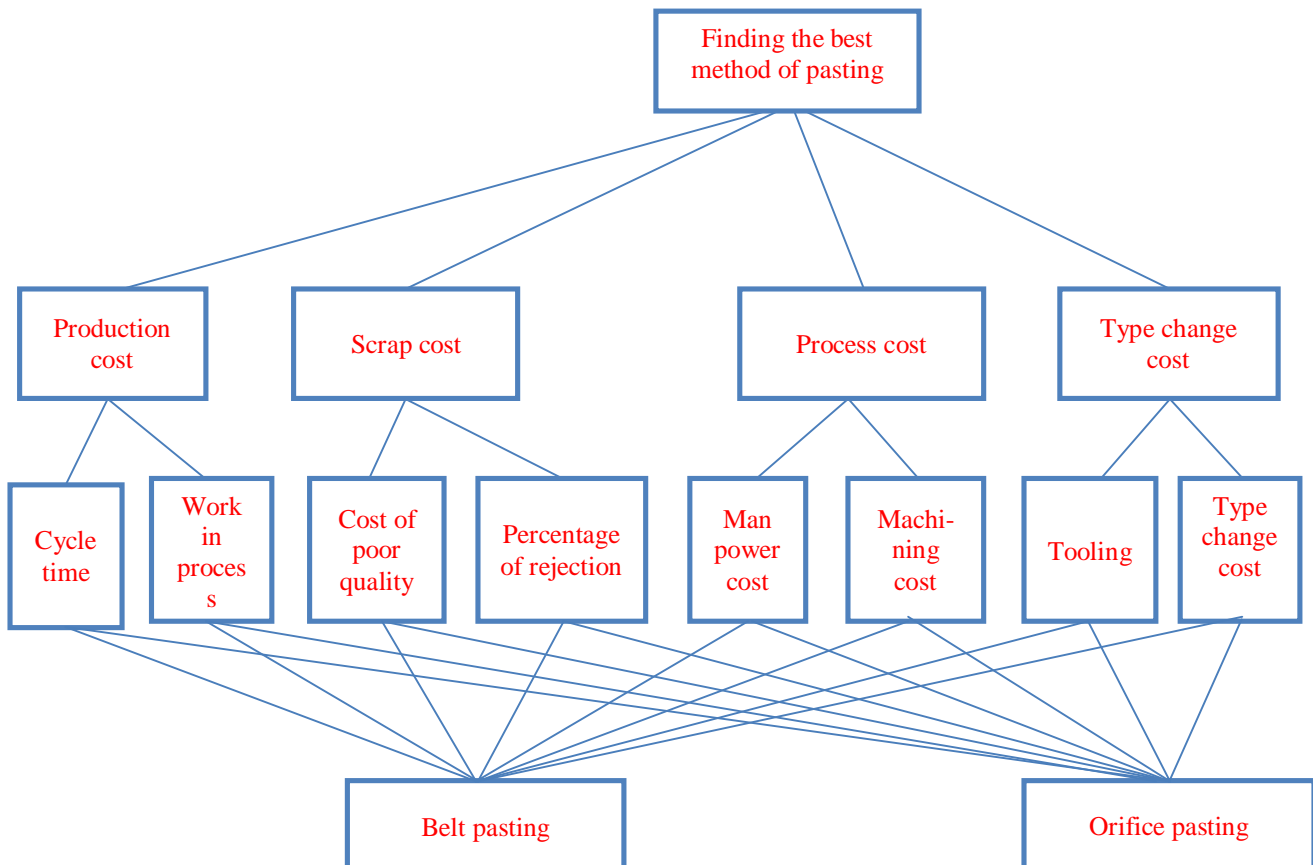
**Table 1:** Definition and membership function of fuzzy number as per Ayag

Intensity of importance	Fuzzy number	Definition	Membership function
1	$\tilde{1}$	Equally important/preferred	(1,1,2)
3	$\tilde{3}$	Moderately more important/preferred	(2,3,4)
5	$\tilde{5}$	Strongly more important/preferred	(4,5,6)
7	$\tilde{7}$	Very strongly more important/preferred	(6,7,8)
9	$\tilde{9}$	Extremely more important/preferred	(8,9,10)

Fundamental scale used in pair wise comparison as per Satty

## III. APPLICATION OF FUZZY AHP FOR THE CASE STUDY

By considering the criteria and sub-criteria involved in the pasting process are used to find the best pasting method. The hierarchal structure is shown below. In the present work we consider both qualitative and quantitative criteria. Fuzzy AHP methodology has been applied to obtain priority vectors for each alternative which are subsequently employed to obtain global vectors.



**Fig 1:** Hierarchy of considered case study

#### IV. CASE STUDY

A case study has been conducted in the battery manufacturing unit of Industrial Battery Division (IBD), Amara Raja Batteries Limited at Karakambadi, Tirupathi.

Amara Raja Batteries Limited was established in the year 1985 as private limited and then converted into public limited in the year 1990. The company is currently poised on a healthy growth curve and ended the financial year 2007 – 08 with a turnover of Rs.745 cores with a profit of 47 cores.

It has a strategic tie up with Johnson Control Inc. of the USA who owns 26% stake in this company. Johnson Controls is a Fortune 500 company and also the largest manufacturer of lead acid batteries in North America and a leading global supplier to major automobile manufacturers and industrial customers.

#### Solution Procedure of Fuzzy AHP

Fuzzy AHP has the standard solution procedure for calculating priority vectors, global vector. The step by step procedure is as follows

**Step1:** Developing the Fuzzy comparison matrix for the resources required for the activities using triangular fuzzy numbers.

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- Step2:** Developing the  $\alpha$ -cuts fuzzy comparison matrix for the activities ( $\alpha = 0.5, \mu = 0.5$ )
- Step3:** Developing the normalized comparison matrix for the Fuzzy comparison matrix by dividing the each element in the column by the sum of that particular column.
- Step4:** Establishing priority vector
- Step5:** Comparison of alternatives
- Step6:** Calculating priority vector for alternatives
- Step7:** Obtaining the global vector
- Step8:** Selecting the best alternative in consideration of global vector

From Table 2 to Table 14, the detailed calculations of Fuzzy comparison matrix,  $\alpha$ -cut Fuzzy comparison matrix, normalized matrix and their corresponding CI, CR are shown.

The main criteria for the considered case study are production cost, scrap cost, process cost and type change cost. Priority vectors for the criteria are further developed to calculate  $\alpha$ -cut Fuzzy comparison, normalized matrices as shown in Table 2.

**Table 2:** Development of Fuzzy priority vector for the criteria

	Production Cost	Scrap cost	Process cost	Type change cost
Production Cost	1	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{9}$
Scrap cost	$\frac{1}{3}$	1	$\frac{1}{5}$	$\frac{1}{9}$
Process Cost	$\frac{1}{3}$	$\frac{1}{5}$	1	$\frac{1}{3}$
Type change Cost	$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{3}$	1
<b><math>\alpha</math>-cut Fuzzy comparison matrix</b>				
	Production cost	Scrap cost	Process cost	Type change cost
Production cost	1	(1/4,1/2)	(1/4,1/2)	(1/10,1/8)
Scrap cost	(2,4)	1	(1/6,1/4)	(1/10,1/8)
Process cost	(2,4)	(4,6)	1	(1/4,1/2)
Type change cost	(8,10)	(8,10)	(2,4)	1
<b>Normalised Fuzzy matrix</b>				
	Production cost	Scrap cost	Process cost	Type change cost
Production cost	0.0625	0.024	0.081	0.07
Scrap cost	0.187	0.065	0.045	0.07
Process cost	0.187	0.325	0.218	0.234
Type change cost	0.562	0.585	0.654	0.625

Production cost has two sub-criteria. They are cycle time and work in process. Their principal vectors, consistency index and consistency ratio are as shown in Table 3.

**Table 3:** Production cost sub-criteria analysis

<b>Fuzzy comparison matrix</b>				
	Cycle time	Work in process		
Cycle time	1	$\frac{1}{5}$		
Work in process	$\frac{1}{5}$	1		
<b><math>\alpha</math>-cut Fuzzy comparison matrix</b>				
	Cycle time	Work in process		
Cycle time	1	(1/6,1/4)		
Work in process	(4,6)	1		
<b>Normalised Fuzzy matrix</b>				
	Cycle time	Work in process	Sum	Principal vector
Cycle time	0.167	0.167	0.334	0.167
Work in process	0.83	0.83	1.66	0.83
			C.I = 0	
			C.R = 0	

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Cost of poor quality and percentage of rejection are sub-criteria of scrap cost. Priority vectors are considered further to calculate normalized matrix and consistency as shown in Table 4.

**Table 4:** Scrap cost sub-criteria analysis

Fuzzy comparison matrix				
	Cost of poor quality	Percentage of rejection		
Cost of poor quality	1	$\frac{1}{3}$		
Percentage of rejection	$\frac{1}{3}$	1		
$\alpha$ -cut Fuzzy comparison matrix				
Cost of poor quality	1	(1/4,1/2)		
Percentage of rejection	(2,4)	1		
Normalised Fuzzy matrix				
	Cost of poor quality	Percentage of rejection	Sum	Principal vector
Cost of poor quality	0.25	0.27	0.52	0.26
Percentage of rejection	0.75	0.72	1.47	0.74
			C.I = 0	
			C.R = 0	

Man power cost and machining cost comes under the sub-criteria of process cost. Machining cost is strongly preferred than man power cost and it also satisfies the consistency as shown in Table 5.

**Table 5:** Process cost sub-criteria analysis

Fuzzy comparison matrix				
	Man power cost	Machining cost		
Man power cost	1	$\frac{1}{5}$		
Machining cost	$\frac{1}{5}$	1		
$\alpha$ -cut Fuzzy comparison matrix				
Man power cost	1	(1/6,1/4)		
Machining cost	(4,6)	1		
Normalised Fuzzy matrix				
	Man power cost	Machining cost	Sum	Principal vector
Man power cost	0.167	0.167	0.334	0.167
Machining cost	0.83	0.83	1.66	0.83
			C.I = 0	
			C.R = 0	

Tooling cost & type change cost are the criteria of type change cost. Their consistency is calculated as below in Table 6

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**Table 6:** Type change cost sub-criteria analysis

Fuzzy comparison matrix				
	Tooling cost	Type change cost		
Tooling cost	1	$\frac{1}{3}$		
Type change cost	3	1		
$\alpha$ -cut Fuzzy comparison matrix				
Tooling cost	1	(1/4,1/2)		
Type change cost	(2,4)	1		
Normalised Fuzzy matrix				
	Tooling cost	Type change cost	Sum	Principal vector
Tooling cost	0.25	0.27	0.52	0.26
Type change cost	0.75	0.72	1.47	0.74
			C.I = 0	
			C.R = 0	

The two available alternatives are Belt pasting and Orifice pasting. For each sub-criteria, the priority vectors of Belt pasting and Orifice pasting are considered to calculate the principal vectors in order to check the consistency as shown below from Table 7 to Table 14.

**Table 7:** Cycle time alternatives analysis

Fuzzy comparison matrix				
	Belt pasting	Orifice pasting		
Belt pasting	1	$\frac{1}{3}$		
Orifice pasting	3	1		
$\alpha$ -cut Fuzzy comparison matrix				
Belt pasting	1	(1/4,1/2)		
Orifice pasting	(2,4)	1		
Normalised Fuzzy matrix				
	Belt pasting	Orifice pasting	Sum	Principal vector
Belt pasting	0.25	0.27	0.52	0.26
Orifice pasting	0.75	0.72	1.47	0.74
			C.I = 0	
			C.R = 0	

**Table 8:** Work in process alternatives analysis

Fuzzy comparison matrix				
	Belt pasting	Orifice pasting		
Belt pasting	1	$\frac{1}{5}$		
Orifice pasting	5	1		
$\alpha$ -cut Fuzzy comparison matrix				
Belt pasting	1	(1/6,1/4)		
Orifice pasting	(4,6)	1		
Normalised Fuzzy matrix				
	Belt pasting	Orifice pasting	Sum	Principal vector
Belt pasting	0.167	0.167	0.334	0.167
Orifice pasting	0.83	0.83	1.66	0.83
			C.I = 0	
			C.R = 0	

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**Table 9:** Cost of poor quality alternatives analysis

Fuzzy comparison matrix				
	Belt pasting	Orifice pasting		
Belt pasting	1	$\frac{1}{3}$		
Orifice pasting	$\frac{1}{3}$	1		
$\alpha$ -cut Fuzzy comparison matrix				
Belt pasting	1	(1/4,1/2)		
Orifice pasting	(2,4)	1		
Normalised Fuzzy matrix				
	Belt pasting	Orifice pasting	Sum	Principal vector
Belt pasting	0.25	0.27	0.52	0.26
Orifice pasting	0.75	0.72	1.47	0.74
			C.I = 0	
			C.R = 0	

**Table 10:** Percentage of rejection alternatives analysis

Fuzzy comparison matrix				
	Belt pasting	Orifice pasting		
Belt pasting	1	$\frac{1}{3}$		
Orifice pasting	$\frac{1}{3}$	1		
$\alpha$ -cut Fuzzy comparison matrix				
Belt pasting	1	(1/4,1/2)		
Orifice pasting	(2,4)	1		
Normalised Fuzzy matrix				
	Belt pasting	Orifice pasting	Sum	Principal vector
Belt pasting	0.25	0.27	0.52	0.26
Orifice pasting	0.75	0.72	1.47	0.74
			C.I = 0	
			C.R = 0	

**Table 11:** Man power cost alternatives analysis

Fuzzy comparison matrix				
	Belt pasting	Orifice pasting		
Belt pasting	1	$\frac{1}{3}$		
Orifice pasting	$\frac{1}{3}$	1		
$\alpha$ -cut Fuzzy comparison matrix				
Belt pasting	1	(1/4,1/2)		
Orifice pasting	(2,4)	1		
Normalised Fuzzy matrix				
	Belt pasting	Orifice pasting	Sum	Principal vector
Belt pasting	0.25	0.27	0.52	0.26
Orifice pasting	0.75	0.72	1.47	0.74
			C.I = 0	
			C.R = 0	

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**Table 12: Machining cost alternatives analysis**

Fuzzy comparison matrix				
	Belt pasting	Orifice pasting		
Belt pasting	1	$\tilde{7}^{-1}$		
Orifice pasting	$\tilde{7}$	1		
$\alpha$ -cut Fuzzy comparison matrix				
Belt pasting	1	(1/8,1/6)		
Orifice pasting	(6,8)	1		
Normalised Fuzzy matrix				
	Belt pasting	Orifice pasting	Sum	Principal vector
Belt pasting	0.125	0.127	0.252	0.126
Orifice pasting	0.875	0.874	1.749	0.874
			C.I = 0	
			C.R = 0	

**Table 13: Tooling cost alternatives analysis**

Fuzzy comparison matrix				
	Belt pasting	Orifice pasting		
Belt pasting	1	$\tilde{7}^{-1}$		
Orifice pasting	$\tilde{7}$	1		
$\alpha$ -cut Fuzzy comparison matrix				
Belt pasting	1	(1/8,1/6)		
Orifice pasting	(6,8)	1		
Normalised Fuzzy matrix				
	Belt pasting	Orifice pasting	Sum	Principal vector
Belt pasting	0.125	0.127	0.252	0.126
Orifice pasting	0.875	0.874	1.749	0.874
			C.I = 0	
			C.R = 0	

**Table 14: Type change cost alternatives analysis**

Fuzzy comparison matrix				
	Belt pasting	Orifice pasting		
Belt pasting	1	$\tilde{7}^{-1}$		
Orifice pasting	$\tilde{7}$	1		
$\alpha$ -cut Fuzzy comparison matrix				
Belt pasting	1	(1/8,1/6)		
Orifice pasting	(6,8)	1		
Normalised Fuzzy matrix				
	Belt pasting	Orifice pasting	Sum	Principal vector
Belt pasting	0.125	0.127	0.252	0.126
Orifice pasting	0.875	0.874	1.749	0.874
			C.I = 0	
			C.R = 0	

From the above tables, it is clear that all the CR values are less than 0.1. Therefore, the consistencies are in the satisfied range.



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## V. RESULTS AND DISCUSSIONS

As the consistencies are satisfied, we can go for the calculation of global vectors. They are shown below in Table 15.

Table 15: Global vector of alternatives

S.No.	Sub-criteria description	Weight of sub-criteria(A)	Criteria weight	Belt pasting (X)	Orifice pasting (Y)	A.B (C)	C.X	C.Y
1	Cycle time	0.167	0.0558	0.26	0.74	0.0093	0.0024	0.0068
2	Work in process	0.83	0.0558	0.167	0.83	0.046	0.0076	0.038
3	Cost of poor quality	0.26	0.0802	0.26	0.74	0.0209	0.0054	0.015
4	Percentage of rejection	0.74	0.0802	0.26	0.74	0.0593	0.0154	0.043
5	Man power cost	0.167	0.2425	0.26	0.74	0.04	0.0104	0.0296
6	Machining cost	0.83	0.2425	0.125	0.874	0.201	0.025	0.175
7	Tooling cost	0.26	0.621	0.125	0.874	0.162	0.0202	0.141
8	Type change cost	0.74	0.621	0.125	0.874	0.46	0.0575	0.402
	Decision index					Sum	0.1439	0.8504

From the above table, the decision index for Belt pasting and Orifice pasting are **0.1439** and **0.8504**. The one with the highest global vector is considered as the best method.

Orifice pasting has the highest global vector. So it is considered as the best pasting method in pasting of a battery plate.

## VI. CONCLUSION

A case study has been taken from the battery manufacturing unit of an organization. To find out the best pasting method in pasting of a battery plate, the criteria and sub-criteria are considered. Using Fuzzy Analytical Hierarchy Process (Fuzzy AHP), the priority vectors for alternatives and their corresponding global vector is calculated. The alternative which is having the highest global vector is taken as the best alternative. From the above analysis, decision index for Belt pasting and Orifice pasting are 0.1439 and 0.8504. So we can conclude that Orifice pasting is the best pasting method.

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