Journal of Engineering
Research and Education
Vol. 8 (2016) 73-84

Application of fuzzy AHP for setup reduction in manufacturing industry

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ABSTRACT

Traditionally, setup time is regarded as one of the most expensive costs that manufacturing firms and organizations had to face including for the optimizations of the setup processes and for the huge production lots. Faster setups ensure numerous benefits beyond smaller lot sizes, including lower labor costs, higher effective capacity and more flexibility, all of which are critical for response to market forces such as rising product variety and customization. Many methods and concepts are being implemented as a medium for setup time reduction including Multiple Criteria Decision Making (MCDM) techniques. One of the famous technique that are being applied is Fuzzy Analytic Hierarchy Process (Fuzzy-AHP). This paper presents a comprehensive application of Fuzzy-AHP in a setup time reduction problem. For the sake of implementation, a case study of selecting the best improvement strategy for reducing time in cleaning Drilling Router Jig (DRJ) and composite panel in a setup process for 5-axis composite material's trimming machine in a composite manufacturing company was presented. Data analysis was presented to show the final results. The highest score of alternatives with respect to all criteria indicates the best option.

Keywords - Setup time reduction, SMED, Single Minute Exchange of Dies, lean manufacturing, Multiple Criteria Decision Making, MCDM, Analytic Hierarchy Process, AHP.

INTRODUCTION

For the last decades, the need for setup time reduction has become a sine qua non especially in production lines with a wide variety of products [(1–4)]. Setup is commonly treated as "black box" by management science literature, assuming a mathematical functional relationship between the setup time and its variance, or more strictly its anticipated value [(5)]. Setup reduction is an essential feature of the continuous improvement program of any manufacturing organizations especially if

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they expect to respond to changes such as shortened lead times, smaller lot sizes and higher quality standards (6-7).

Various type of methods and techniques can be used as a medium for setup time reduction including Multiple Criteria Decision Making (MCDM) method [8]. MCDM refers to the set of methods and techniques which deal with the evaluation of a set of alternatives with respect to a set of decision criteria to make complex decisions in a systematic and structured way (9–11).The purpose of MCDM is to develop a choice, ranking, sorting and in most of cases an order of alternatives, from the most preferred one to the least preferred option (12–14).

One of the classical MCDM tool is Analytic Hierarchy Process (AHP), which was first developed by Saaty (15) by integrating expert's opinions and evaluation scores into a simple elementary hierarchy system. The main idea of AHP is weighting the criteria and alternatives by using pairwise comparison concept respect to each other (16-17). By capture both subjective and objective assessment measures of the available options, AHP can reduce bias in decision making (18).

However, in many practical cases of the AHP, the human preference model is uncertain and decision makers might be unable to choose exact numerical values for comparison judgements (19). Since basic AHP does not include the uncertainty and vagueness of expert's judgement, this impreciseness of human judgements can be handled by benefiting from fuzzy sets theory developed by Zadeh (20) .The Fuzzy AHP method basically integrating the basic AHP concept into fuzzy domain by using fuzzy numbers for pairwise comparison instead of real numbers. The pairwise comparison for both criteria and alternatives are performed through the linguistic variables which are represented by triangular numbers (16, 21).

Therefore, this paper presents a comprehensive application of Fuzzy AHP in the case study problem which is to select the best improvement strategy for reducing time in cleaning Drilling Router Jig (DRJ) and composite panel in order to reduce the setup time for 5-axis composite material's trimming machine in a composite manufacturing company.

RESEARCH METHODOLOGY

This section comprising the description of problem in the case study followed by each procedure of the Fuzzy AHP method. All calculations of pair wise comparison between criteria will be explained in next section.

CASE STUDY

The chosen case study associates with a setup process of a 5-axis trimming machine in a composite materials manufacturing company. In the considered case study, the cleaning process of Drilling Router Jig (DRJ) and composite panel was taken place during the setup process. Currently, the top management of the company decided to do improvement by cleaning DRJ and composite panel during the trimming operation of previous composite panel but they are experiencing some difficulties in choosing the best area to place the cleaned DRJ and composite panel before they are needed. Fuzzy AHP method has been applied in order to select the best decision in solving the problem.

Fuzzy AHP methodology

The pair wise comparisons of both criteria and the alternatives in the Fuzzy AHP are accomplished through the linguistic variables, symbolised by triangular numbers. Despite that there are many techniques embedded in Fuzzy AHP, the Buckley's methods (22) is implemented in this scope of research study due to its simplicity. The steps of the procedure for Fuzzy AHP are as follows:

Step 1: Hierarchy construction

The hierarchy is composed of different levels, from the objectives, through varieties of criteria to set of alternatives. Related criteria and the alternatives which refers to the selection of three possible alternatives are defined according to the goal, which is to select the best improvement strategy for reducing time in cleaning Drilling Router Jig (DRJ) and composite panel. The constructed hierarchy for the case study problem is shown in Figure 1 below.

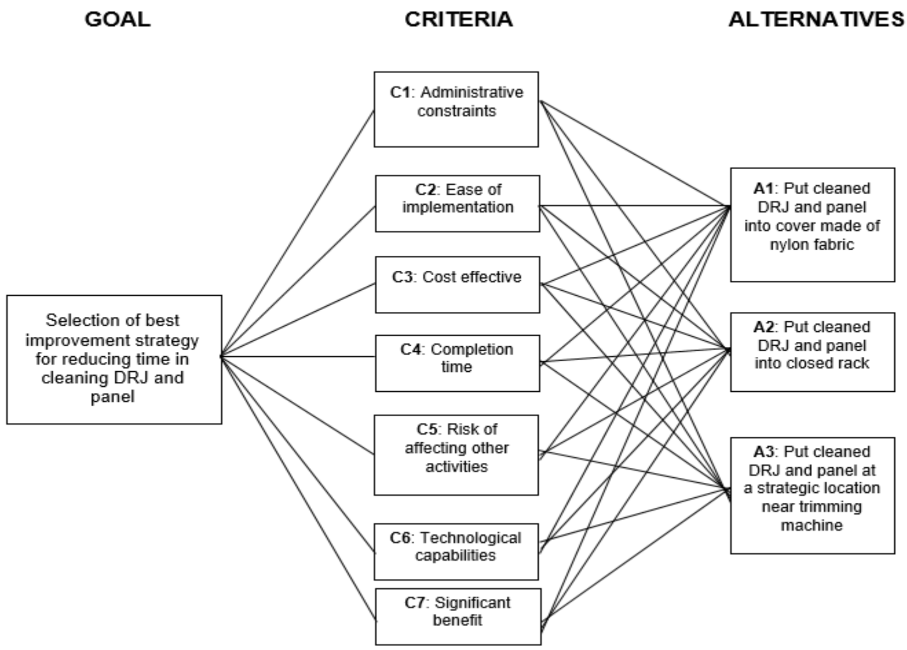

Figure 1: Hierarchy for selecting the best improvement strategy to reduce time in cleaning DRJ and panel

Step 2: Pairwise comparison matrices between criteria

Fuzzy triangular scales are used to determine the priorities of the criteria in the hierarchy reflecting the relative importance among other criteria. The criteria or alternatives are compared by using linguistic terms as shown in Table 1 below.

Table 1: Linguistic terms and the corresponding triangular fuzzy scale

Saaty scale	Linguistic terms	Fuzzy Triangular Scale
1	Equally important (Eq. Imp.)	(1,1,1)
3	Weakly important (W. Imp.)	(2,3,4)
5	Fairly important (F. Imp.)	(4,5,6)
7	Strongly important (S. Imp.)	(6,7,8)
9	Absolutely important (A. Imp.)	(9,9,9)
2	The intermittent values between two adjacent scales	(1,2,3)
4		(3,4,5)
6		(5,6,7)
8		(7,8,9)

The pairwise comparisons between all criteria were made by using a data from sets of questionnaire participated by three workers who are dealing with the setup process. The collected data were averaged to compile the opinion from all of three decision makers. The pair wise comparison data of each criteria towards each other in triangular scale from Table 2 were then synthesized into matrices contribution form as in Table 3. For instance, if the decision maker states that Criteria 1 is “Weakly Important” than Criteria 2, then the corresponding triangular scale in pair wise contribution matric will be (2, 3, 4). On the contrary, the inverse pair wise comparison matric of Criteria 2 to Criteria 1 is (1/4,1/3,1/2).

Table 2: Pairwise comparison among all the criteria involved in the hierarchy

Q#	A. Imp (9,9,9)	S. Imp (6,7,8)	F. Imp (4,5,6)	W. Imp (2,3,4)	CRI TERIA	Eq. Imp (1,1,1)	CRI TERIA	W. Imp (2,3,4)	F. Imp (4,5,6)	S. Imp (6,7,8)	A. Imp (9,9,9)
1					C1		C2				
2					C1		C3				
3					C1		C4				
4					C1		C5				
5					C1		C6				
6					C1		C7				
7					C2		C3				
8					C2		C4				
9					C2		C5				
10					C2		C6				
11					C2		C7				
12					C3		C4				
13					C3		C5				
14					C3		C6				
15					C3		C7				
16					C4		C5				
17					C4		C6				
18					C4		C7				
19					C5		C6				
20					C5		C7				
21					C6		C7				

Table 3: Pair wise contribution matrices for all criteria

CRI	C1	C2	C3	C4	C5	C6	C7
C1	(1,1,1)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/6,1/5,1/4)
C2	(2,3,4)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(2,3,4)	(1/4,1/3,1/2)
C3	(4,5,6)	(2,3,4)	(1,1,1)	(4,5,6)	(1/4,1/3,1/2)	(4,5,6)	(1/4,1/3,1/2)
C4	(2,3,4)	(2,3,4)	(1/6,1/5,1/4)	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	(1/4,1/3,1/2)
C5	(4,5,6)	(4,5,6)	(2,3,4)	(2,3,4)	(1,1,1)	(2,3,4)	(1,1,1)
C6	(2,3,4)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/6,1/5,1/4)
C7	(4,5,6)	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)	(4,5,6)	(1,1,1)

Step 3: Normalized relative weights of criteria

In this step, the geometric means of fuzzy comparison value $(\widetilde{r_1})$ were calculated as shown in Table 4 and the example calculation for 'Criteria 1' is calculated as Eq. 1.

$$\widetilde{r_i} = \left(\prod_{j=1}^{n} \widetilde{d_{ij}} \right)^{\mathbf{1/n}}$$

$$= [(1 * 1/4 * 1/6 * 1/4 * 1/6 * 1/4 * 1/6)^{1/7} \;;\; (1 * 1/3 * 1/5 * 1/3 * 1/5 * 1/3 * 1/5)^{1/7} ; (1 * 1/2 * 1/4 * 1/2 * 1/4 * 1/2 * 1/4)^{1/7}]$$

$$= [0.256 \;;\; 0.313 \;;\; 0.410] \qquad (1)$$

Table 4: Geometric means of fuzzy comparison values

CRITERIA		$\widetilde{r_i}$	
C1	0.256	0.313	0.410
C2	0.521	0.679	0.906
C3	1.346	1.704	2.155
C4	0.701	0.930	1.219
C5	2.000	2.536	3.022
C6	0.365	0.461	0.610
C7	2.000	2.536	3.022
Total	7.190	9.160	11.344
Reverse (Power of -1)	0.139	0.109	0.088
Increasing order	0.088	0.109	0.139

The geometric means of fuzzy values were then converted to relative fuzzy of weight as shown in Table 5 by multiplying them with the total of reverse fuzzy geometric means in increasing order by using Eq. 2.

$$\widetilde{w_i} = [(0.256*0.088); (0.313*0.109); (0.410*0.139)] = [0.023 ; 0.034 ; 0.057] \quad (2)$$

Table 5: Relative fuzzy weight of each criteria

CRITERIA	$\widetilde{w_i}$		
C1	0.023	0.034	0.057
C2	0.046	0.074	0.126
C3	0.118	0.186	0.300
C4	0.062	0.101	0.169
C5	0.176	0.276	0.420
C6	0.032	0.050	0.085
C7	0.176	0.276	0.420

Finally, the relative non-fuzzy weight of each criteria (M_i) is calculated by averaging the fuzzy numbers for each criteria. The normalized weights of each criteria, (N_i) were calculated by dividing the each value of relative fuzzy weight with the total of all criteria's value. Hence, the av

eraged and normalized weight of criteria are shown in Table 5.

Table 5: Averaged and normalized relative weight of criteria

CRITERIA	M_i	N_i
C1	0.038	0.035
C2	0.082	0.077
C3	0.201	0.188
C4	0.111	0.104
C5	0.291	0.272
C6	0.056	0.052
C7	0.291	0.272

RESULTS AND DISCUSSION

Fuzzy AHP result

By using the same step as before, the pairwise comparison step was repeated but this time all of the three alternatives are compared with respect to each criterion.

However, it will be burdensome to describe all of the calculations as it follows the same step as the pair wise comparison of each criterion with respect to other criterion. The final results of total score for each alternative are shown in Table 6 below.

Table 6: Aggregated results for each alternative according to each criterion

CRITERIA		Scores of Alternatives with respect to related Criterion		
	Weights (N_i)	A1	A2	A3
C1. Administrative constraints	0.035	0.575	0.284	0.140
C2. Ease of implementation	0.077	0.202	0.597	0.202
C3. Cost	0.188	0.284	0.140	0.575
C4. Completion time	0.104	0.202	0.202	0.597
C5. Risk	0.272	0.597	0.202	0.202
C6. Technological capabilities	0.052	0.202	0.202	0.597
C7. Significant benefit	0.272	0.202	0.202	0.597
TOTAL (Score Alt x weight criteria)		*0.338*	*0.224*	*0.439*

From Table 7, it is clearly shown that Alternative 3, which is to put the cleaned DRJ and composite panel at a strategic place near trimming machine is the best choice among other alternatives according to its highest score. Therefore, it is suggested as the best strategy to be implemented for reducing time in cleaning Drilling Router Jig (DRJ) and composite panel with respect to seven criteria and fuzzy preferences of decision makers. However, Alternative 1 can be selected as the second best alternative as it acquired second highest score.

Table 7: Alternative's final ranking

Alternative	Description	Percentages	Rank
A1	Put cleaned DRJ and composite panel into cover made of nylon fabric	33.8%	2
A2	Put cleaned DRJ and composite panel into closed rack	22.4%	3
A3	Put cleaned DRJ and composite panel at a strategic location near trimming machine	43.9%	1

CONCLUSIONS

1. This paper presented the application of Fuzzy Analytic Hierarchy Process (F-AHP) in selecting the best improvement strategy to be implemented in reducing the setup time for 5-axis trimming machine in manufacturing industry.
2. Fuzzy AHP is effective in selecting the best alternative by determining the relative importance of a set of criteria with alternatives, which in this case study refers to the selection of best improvement strategy for reducing time in cleaning Drilling Router Jig (DRJ) and composite panel.
3. Fuzzy AHP takes into considerations several factors that affect the decision making process including administrative constraints, ease of implementation, cost, completion time, risk affecting other activities, technological capabilities and significant benefit in reducing setup time.
4. There are many types of setup time reduction problem that can be solved by using Multiple Criteria Decision Making (MCDM) techniques such as Fuzzy AHP but they must be utilized according to the suitability of the problem in order to develop the best decision. However, since the problem in this case study involved single sourcing type, the complicated techniques are not required to be performed.

ACKNOWLEDGEMENT

The authors wish to appreciate the professional collaboration that has been given by the case study company in completing this research. Also, authors wish to acknowledge the support from Universiti Malaysia Perlis via Research Accultration Grant Scheme (RAGS), Grant No; 9018-00076. The authors also thank the referees for their useful suggestions.

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