Presented at the DLSU Research Congress 2016
De La Salle University, Manila, Philippines
March 7-9, 2016

A Fuzzy Analytic Hierarchy Process Approach for Optimal Selection of Manufacturing Layout

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Abstract: Selection of the right layout design is critical in any manufacturing company. With the right layout design, productivity can increase, lead time and non-value added operations can be minimized, and flow of materials can be streamlined. Proper arrangement of departments and machines directly contributes to the reduction of material handling cost and improvement of overall efficiency. Manufacturing layout requires large capital investment and long-term planning horizon and costs cannot be avoided if modification of an existing layout is necessary. In this study, the fuzzy Analytic Hierarchy Process (FAHP) is thus applied in the selection of the best manufacturing layout that integrates both quantitative and qualitative criteria in the decision structure. AHP is a widely used multi-criteria decision analysis that decomposes the decision problem in a hierarchical structure and derives priorities from the value judgment of individual or a group in decision making. However, the conventional method of AHP has limitation in addressing the vagueness of subjective judgment. Variant of Fuzzy AHP was thus developed and applied to model the vagueness of judgment by representing the verbal scale in terms of fuzzy numbers. To illustrate the method, a case study was conducted in a company located in Cavite which manufactures bolo knives. Layout alternatives were generated using Systematic Layout Planning (SLP). The criteria used for the decision model are productivity, initial investment, flexibility and ease of maintenance for the optimal selection of manufacturing layout. Results of the FAHP-based decision model were then presented in this paper.

Key Words: facility layout selection; multiple-criteria decision making; fuzzy analytic hierarchy process

1. INTRODUCTION

Facility layout design plays an important role in improving productivity, material handling, machine and space utilization. An inefficient layout leads to more transportation, handling and storage costs. For companies to survive the competition in the market, non-value added costs due to inefficiencies should be reduced. For several decades, facility layout improvement has been an active area for research. There are still many challenges related to the achievement of the most efficient layout design. Different methodologies have been used to provide solutions to various layout problems. The most common approach is the use of System Layout Planning (SLP). This approach can incorporate both qualitative and quantitative objectives of the design process (Muther, 1973). The three fundamental areas of this approach relationships, space and adjustments. Relationship area is a collection of input data, flow of materials and activity relationships. The space area refers to the space requirements, space available and space relationship diagram. Lastly, the adjustment area includes modifying considerations, practical limitations, evaluation and final selection. However, the traditional relationship chart often represents closeness of ratings among departments in facility. Usually these ratings are vague in terms of quantitative and qualitative factors that may affect the assignment of ratings. In real situation, there are multiple criteria that may affect the decision making process for the selection of the most appropriate layout design.

One approach that has been developed and is now widely used is the fuzzy AHP (Analytic Hierarchy Processes). This methodology aids the decision maker to evaluate various alternatives to come up with the most appropriate decision in facility layout design problems. This paper aims to demonstrate the application of fuzzy AHP (Promentilla et al. 2015) in the selection of layout design alternatives generated from a case study in the manufacturing of metal bolo knives.

Numerous articles have been published regarding the use of fuzzy hierarchical AHP technique. Thomas L. Saaty originally developed AHP during the 1970s as a decision-making tool dealing with complex, unstructured and multiple-attribute decisions. Yang and Kuo (2003) proposed a hierarchical analytic process (AHP) and data envelopment analysis (DEA) approach to solve a plant layout design problem in an IC packaging company. A computer-aided layout-planning tool was used to generate a considerable number of layout alternatives as well as to generate quantitative decision-making unit (DMU) outputs. The qualitative performance measures were weighted using the AHP approach. DEA was then used to solve multiple-objective layout problem. The strength of the methodology is to efficiently evaluate a large number of layout alternatives. The final solution generated is not sensitive to the sample generation process since the sample size of the layout alternatives is quite large. Bacudio et al. (2015) applied AHP to evaluate layout design alternatives generated from a systematic layout planning (SLP) procedure. The methodology involves structuring of hierarchy of criteria and alternatives for evaluation, assessing the decision-maker's evaluation by pairwise comparison, use of eigenvector methodology proposed by Saaty (1980) to yield priorities for criteria and for alternatives by criteria. The scale used for pairwise comparison ranges from 1/9 for "least valued than", to 1 for "equal" to 9 for " absolutely more important." Inconsistency issues were addressed by calculating the consistency ratio (CR).

The development of AHP methodology is continuously evolving as summarized in Ihizaka and Labib (2011). Among the developments is the use of AHP in conjunction with other methodologies such as linear programming, data envelopment analysis, fuzzy sets, genetic algorithm and so on. However, in real world were the environment is more complex and uncertain, decision makers may sometime feel more confident to provide fuzzy judgments than crisp comparisons.

2. METHODOLOGY

The focus of this paper is to provide a more precise judgment using fuzzy AHP. Within the AHP context, the decision maker cannot provide deterministic preferences but perception-based judgment intervals instead. This kind of uncertainty can be modeled using fuzzy set theory (Leung and Cao, 2000). According to Zadeh (1965), fuzzy set is a class of objects with a continuum of grades 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. Kwiesielewicz (1998) showed that the fuzzy pairwise-comparison problem by van Laarhoven and Pedrycz (1983) can be decomposed into two sub problems, namely, the modal values problem and an interval analysis. The approach to the general solution was justified when both the interval analysis sub-problem and the modal values have exactly one degree of freedom. It was shown also that in the general case, the model could not be used when the interval problem has two degrees of freedom. It is necessary to stress that sometimes a solution is not correct in the fuzzy sense when lower, modal and upper values of the solution are not in the proper order.

With various developments in the area of fuzzy AHP, this paper adapts the fuzzy AHP model proposed by Promentilla et al (2015) to evaluate the alternatives generated from a case study in the manufacturing facility of bolo knives.

The steps of fuzzy AHP are as follows:

Step 1: Create a hierarchical decision structure of the decision problem. Fig. 1 shows a three level hierarchical decision structure with *n* criteria and *m* alternatives.

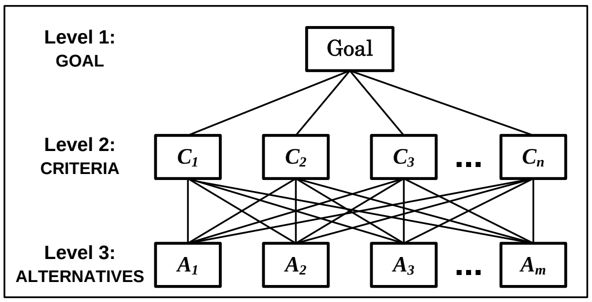

Fig. 1. A hierarchical decision structure

Step 2: Using the linguistic representation of AHP's fundamental 9-point scale modeled by triangular fuzzy numbers (TFN) shown in Table 1, generate the upper triangular pairwise comparison matrix from stakeholder or expert.

Table 1. Linguistic scale of the intensity of dominance of element *i* over element *j* and its corresponding fuzzy number

Fuzzy number $\hat{a}_{ij}$	Linguistic scale for comparison of criteria	Linguistic scale for comparison of alternatives
$\langle \frac{1}{1+\delta}, 1, 1+\delta \rangle$	More or less equally important	More or less equally preferred
$\langle 3-\delta, 3, 3+\delta \rangle$	Moderately more important	Moderately preferred
$\langle 5-\delta, 5, 5+\delta \rangle$	Strongly more important	Strongly preferred
$\langle 7-\delta, 7, 7+\delta \rangle$	Very strongly more important	Very strongly preferred
$\langle 9-\delta, 9, 9+\delta \rangle$	Extremely more important	Extremely more important

A fuzzy judgment $\hat{a}_{ij}$ is represented by three numbers: lower bound (l_{ij}), modal value (m_{ij}), and upper bound (u_{ij}). The degree of confidence in judgement by the stakeholder or expert is represented by δ. Lower δ means higher degree of confidence. Table 2 shows the linguistic scale for the degree of confidence.

Table 2. Degree of confidence linguistic scale

δ	Degree of confidence
0.5	high
1	moderate
2	low

The lower triangular pairwise comparison matrix is derived using Eq. 1.

$$\hat{a}_{ji} = \frac{1}{\hat{a}_{ij}} = \langle \frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}} \rangle \quad \text{(Eq. 1)}$$

Eq. 2 shows the general form of a complete fuzzy AHP pairwise comparison matrix.

$$\hat{A} = \begin{bmatrix} \langle 1,1,1 \rangle & \hat{a}_{12} & \cdots & \hat{a}_{1n} \\ \hat{a}_{21} & \langle 1,1,1 \rangle & \cdots & \hat{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \hat{a}_{n1} & \hat{a}_{n2} & \cdots & \langle 1,1,1 \rangle \end{bmatrix} \quad \text{(Eq. 2)}$$

Step 3: Derived the crisp priority vector ***w*** by solving the nonlinear programming (NLP) formulation proposed by Promentilla et al. (2014) as shown in Fig. 2. A positive λ indicates a consistent fuzzy pairwise comparison matrix and λ = 1 indicates perfect consistency.

Step 4: Compute global priority weights of alternatives with respect to the goal using Eq. 3.

$$w_{AG} = w_{AC} w_{CG} \quad \text{(Eq. 3)}$$

where:

w_{AG} = global priority weights of alternative with respect to goal matrix
w_{AC} = priority weights of alternatives with respect to each criterion matrix
w_{CG} = importance weights of criteria with respect to goal matrix

ISSN 2449-3309

Max λ

Subject to:

$$a_{ij} - l_{ij} \geq \lambda(m_{ij} - l_{ij})$$

$$a_{ji} - l_{ji} \geq \lambda(m_{ji} - l_{ji})$$

$$u_{ij} - a_{ij} \geq \lambda(u_{ij} - m_{ij})$$

$$u_{ji} - a_{ji} \geq \lambda(u_{ji} - m_{ji})$$

$$a_{ij} = \frac{w_i}{w_j}$$

$$a_{ijji} = \frac{w_j}{w_i}$$

for i = 1, ..., n – 1; j = 2, ..., n; j > i

$$\sum_{k=1}^{n} w_k = 1$$

$$w_k \geq 0$$

Fig. 2. Nonlinear programming formulation to maximize λ

3. RESULTS AND DISCUSSION

Bacudio et al. (2015) presented a case study applying AHP to evaluate layout design alternatives generated from the systematic layout planning procedure. Though the study provided a comprehensive evaluation of alternatives using traditional AHP, it failed to establish the impact of assigning subjective values. Fuzzy AHP is applied to address such a gap when subjective judgments affect the decision making process.

Fig. 3 shows the hierarchical structure for the selection of the best layout design in manufacturing metal bolo knives. This paper aims to determine the best alternative considering the four criteria generated from previous studies (Bacudio et al. 2015).

There are four criteria considered in the case study, namely, productivity, initial investment, flexibility and ease of maintenance. Table 3 shows the description of each criterion.

Table 3. Facility layout criteria

Criterion	Description
Productivity	Potential output which can be increased by minimizing non-value asses operations such as preparation and transportation distance
Initial investment	Labor and material costs involved in the relocation of machines
Flexibility	Ability to address demand and product variations
Ease of maintenance	Ability to perform cleaning, repair, and other maintenance at shortest period of time

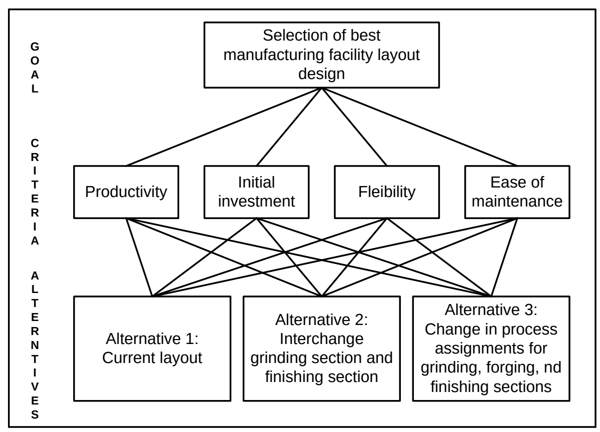

Fig. 3. Decision structure for the selection of best manufacturing layout design

The fuzzy pairwise comparison matrix for the criteria shown in Table 4 is derived from the value judgments of an expert in facility layout management. The importance weights of criteria with respect to the selection of the best alternative layout design are computed by solving the nonlinear programming formulation shown in Fig. 2 using LINGGO 15.0. The computed priority weights of productivity, initial investment, flexibility, and ease of maintenance criteria are 0.5872, 0.2407, 0.0986, and 0.0735, respectively. The computed value of the fuzzy consistence index λ is 0.4398.

Table 4. Fuzzy pairwise comparison matrix of criteria

	Productivity	Initial Investment	Flexibility	Ease of Maintenance
Productivity	$\langle 1,1,1 \rangle$	$\langle 2,3,4 \rangle$	$\langle 3,5,7 \rangle$	$\langle 5,7,9 \rangle$
Initial Investment	$\langle \frac{1}{4},\frac{1}{3},\frac{1}{2} \rangle$	$\langle 1,1,1 \rangle$	$\langle 2,3,4 \rangle$	$\langle 1,3,5 \rangle$
Flexibility	$\langle \frac{1}{7},\frac{1}{5},\frac{1}{3} \rangle$	$\langle \frac{1}{4},\frac{1}{3},\frac{1}{2} \rangle$	$\langle 1,1,1 \rangle$	$\langle \frac{1}{3},1,3 \rangle$
Ease of Maintenance	$\langle \frac{1}{9},\frac{1}{7},\frac{1}{5} \rangle$	$\langle \frac{1}{5},\frac{1}{3},1 \rangle$	$\langle \frac{1}{3},1,3 \rangle$	$\langle 1,1,1 \rangle$

For the quantitative criteria such as productivity and initial investments, weights are derived from actual values and then normalized to derive the preference weights.

The estimated total distance travelled per batch for Alternatives 1, 2, and 3 are 1,086 meters, 713 meters, and 574 meters, respectively. The reduction in distance for Alternatives 2 and 3 leads to reduction in non-value added operations, thus reducing throughput times. The reduction of throughput times for Alternatives 2 and 3 resulted to an increase of 58 and 75 units of output, respectively.

The initial investment required for each alternative is shown in Table 5. The company budget for the initial investment is Php 300,000. Therefore the savings from alternatives 1, 2, and 3 are Php 300,000, Php 202,923, and Php 80,368, respectively.

Table 5. Initial investment

Cost	Alternative 1	Alternative 2	Alternative 3
Material	0	23,802	38,845
Labor	0	73,275	180,787
Total	0	97,077	219,632

Tables 6 and 7 shows the pairwise comparison matrix of alternatives with respect to flexibility and maintenance, respectively. The preference weights of the alternatives with respect to each qualitative criterion such as flexibility and ease of maintenance are derived in the same manner in obtaining priority weights of the different criteria.

Table 6. Pairwise comparison matrix of alternatives with respect to flexibility

Alternative	1	2	3
1	$\langle 1,1,1 \rangle$	$\langle \frac{1}{4},\frac{1}{3},\frac{1}{2} \rangle$	$\langle 2,3,4 \rangle$
2	$\langle 2,3,4 \rangle$	$\langle 1,1,1 \rangle$	$\langle 1,3,5 \rangle$
3	$\langle 2,3,4 \rangle$	$\langle \frac{1}{5},\frac{1}{3},1 \rangle$	$\langle 1,1,1 \rangle$

Table 7. Pairwise comparison matrix of alternatives with respect to ease of maintenance

Alternative	1	2	3
1	1	$\langle \frac{1}{7},\frac{1}{5},\frac{1}{3} \rangle$	$\langle \frac{1}{9},\frac{1}{7},\frac{1}{5} \rangle$
2	$\langle 3,5,7 \rangle$	1	$\langle \frac{1}{4},\frac{1}{3},\frac{1}{2} \rangle$
3	$\langle 5,7,9 \rangle$	$\langle 2,3,4 \rangle$	1

Table 8 shows the normalized performance scores of each alternative with respect to each criterion. The global priority weights of Alternative 1, Alternative 2, and Alternative 3 are 0.3297, 0.3655, and 0.3048, respectively. Therefore, the company should select Alternative 2 as the best layout design.

Table 8. Preference weight for all alternatives

Alternative	Criterion			
	Productivity (0.5872)	Initial Investment (0.2407)	Flexibility (0.0986)	Ease of Maintenance (0.0735)
1	0.2944	0.5143	0.2773	0.0776
2	0.3453	0.3479	0.5931	0.2794
3	0.3603	0.1378	0.1296	0.6430

4. CONCLUSIONS

This paper demonstrated the application of fuzzy AHP in the selection of the best layout design for manufacturing layout design for bolo knives. This approach allows the selection of the best layout based on quantitative and qualitative criteria. This approach was able to address subjective judgment vagueness by representing the verbal scale with fuzzy numbers which is one of the limitations of the traditional AHP method. The degree of confidence was also quantified through the spread of fuzzy numbers. The selection of the best alternative heavily depends on the inputs of the expert in facility layout management. Thus, choosing an expert in the field is critical in achieving the best decision. Future study can include the integration of inputs from the different experts for group decision making.

5. ACKNOWLEDGMENTS

The authors would like to acknowledge Danica Marie Sy for her assistance in gathering information. Special thanks to the management and staff of Hebron Brothers Metal Mfg. Co., Carmona, Cavite.

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