Evaluation of Worker Productivity Improvement Using ISM and FAHP

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Abstract - [*]**In recent years, many printed circuit board manufacturing firms have looked upon worker productivity improvement as the means by which they can improve their firm performance. This paper uses the critical factors and interpretive structural modeling to determine the structure of analytical hierarchical process model in fuzzy environment. Fuzzy analytic hierarchy process-based methodology was used to tackle the different decision criteria in a hierarchical structure in the improvement of worker productivity. The findings advocate that these manufacturing firms would thereby the hierarchical model to setup the priorities of the worker productivity improvement. And best practice, reduce unit cost and physical working environment are the crucial sub-factors for worker productivity improvement.**

Keywords - **Fuzzy analytic hierarchy process, interpretive structural modeling, and worker productivity**

I. INTRODUCTION

Improving worker productivity, which include enhancement of production process design and occupational health and safety (OHS), has become a major concern for industries. Some of the common characteristics of the industries are improper workplace design, ill-structured jobs, mismatch between worker abilities and job demands, poor team work and inappropriate management programs. This results to poor health quality among workers and, in turn, leads to reduced worker productivity and product quality, and increased cost. Ergonomics or human factors application has been found to improve worker productivity, OHS and satisfaction. This has both direct and indirect effects on the overall performance of a company. Hence, it would be extremely difficult to attain company objectives without giving proper consideration to ergonomics.

Effective application of ergonomics in a work system design can be achieved in both physical working environment and psychological conditioning of the workers. An advantage of this is enhanced worker productivity, safety, physical and mental well-being, and job satisfaction. Many research studies have shown positive effects of applying ergonomic principles in workplaces, machine design, job design, environment and facilities design [1-4]. Studies in ergonomics have also produced data and guidelines for industrial applications. The features of ergonomic design of all physical working environment, workstation design, facilities and their corresponding psychological effect are well known [5-7].

However, there is still a need for acceptance because of its limited application in the industry. Worker productivity is not only dependent on ergonomics, but also process management, continuous improvement, team work and work design, mostly well known in total quality management principles [8, 9]. The main concern of process management is usually the improvement of inventory level, achievement of best practice and reduction of product unit cost. Continuous improvement is based on problem solving, track rework and rejects, and modification of existing processes. Team work is considered as the voice of the working group and coordination whereas work design includes development of comfortable workstation, and clear instruction and components. An ergonomically deficient workplace can cause physical and emotional stress, low productivity and poor quality of work. It is believed that production system deficiencies are the root causes of workplace health hazards, low level of safety and reduced worker productivity and quality. The mentioned variables are introduced to the production system as a whole for worker productivity improvement because of its interconnectivity.

Therefore, the objective of this research is to model a hierarchical structure of worker productivity improvement through interpretive structural modeling (ISM) and identify the priority weights of improvement for worker productivity through fuzzy analytic hierarchy process (FAHP).

II. METHODOLOGY

The study problem is concerned with PCB manufacturing firms, aiming to establish a study hierarchical model to be used in prioritizing worker productivity improvement. The firms want to take into account all the important criteria which can affect the implementation prioritization. A decision-making group

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was formed consisting of fifteen (15) experts from each strategic decision area. The PCB professionals were asked to make pairwise comparisons of the criteria and attributes. A questionnaire was provided to get the evaluations. However, a single evaluation was obtained to represent the experts' opinions because the group of experts came up with a consensus using the specified method. This research applies three (3) kinds of research methods; namely, Delphi method, ISM and FAHP.

A. ISM

The ISM proposed by Warfield [10] is a computer-assisted methodology to understand and construct the fundamental relationships of the elements in complex systems or situations. The theory of ISM is based on discrete mathematics, graph theory, social sciences, group decision-making, and computer assistance. The ISM procedure development started through individual or group mental models to calculate binary matrices, also called relation matrix, to present the relations of the elements. Another system, the *Delphi method*, is a technique to arrive at a group position regarding an issue under investigation. It consists of a series of repeated interrogations, usually by means of questionnaires, of a group of individuals whose opinions or judgments are of interest. After the initial interrogation of each individual, each subsequent interrogation is accompanied by information regarding the preceding round of replies, usually presented anonymously. The individual is, thus, encouraged to reconsider and, if appropriate, to change his previous reply in light of the replies of other members of the group. After two or three rounds, the group position is determined by averaging. The method proceeds as follows: (i) Provision for the inclusion of the scientific elements; (ii) Means for exhibiting a complex set of relations; (iii) Means for showing a complex set of relations which permit continuous observation, questioning and modification of the relations; (iv) Congruence with the originators' perceptions and analytical processes; (v) Ease of learning by public (or, by inference, multidisciplinary) audience.

Graphical models, in particular, directed graphs appear to satisfy these requirements. In this representation, the elements or components of a system are represented by the "points" of the graph and the existence of a particular relationship between elements is indicated by the presence of a directed line segment. It is this concept of relatedness in the context of a particular relationship which distinguishes a system from a mere aggregation of components.

A relation matrix can be formed by asking the question like "Does the feature e_i inflect the feature e_j?" If the answer is "Yes" then $d_{ij} = 1$, otherwise $d_{ij} = 0$. The general form of the relation matrix can be presented as below.

$$D = \begin{array}{c} \\ e_1 \\ e_2 \\ . \\ . \\ e_n \end{array} \begin{array}{c} \begin{array}{cccccc} e_1 & e_2 & \cdots & \cdots & e_n \end{array} \\ \begin{pmatrix} 0 & d_{12} & \cdots & \cdots & d_{1n} \\ d_{12} & 0 & \cdots & \cdots & d_{2n} \\ \cdots & \cdots & \cdots & \cdots & . \\ \cdots & \cdots & \cdots & \cdots & . \\ d_{m1} & d_{m2} & \cdots & \cdots & 0 \end{pmatrix} \end{array}$$

Where e_i is the i th element in the system, d_{ij} denotes the relation between i th and j th elements, D is the relation matrix.

After constructing the relation matrix, the reachability matrix can be calculated using (1) and (2).

$$M = D + I \tag{1}$$

$$M^* = M^k = M^{k+1} \quad k>1 \tag{2}$$

Next, the reachability set is calculated and the priority is set based on (3) and (4), respectively.

$$A\,(t\,i) = \{\, t_j \mid m'_{ij} = 1\} \tag{3}$$

$$R\,(t\,i) = \{\, t_j \mid m'_{ij} = 1\} \tag{4}$$

Where m_{ij} denotes the value of the ith row and the jth column.

Then, from (5), the levels and relationships between the elements can be determined and the structure of the elements' relationships can also be expressed using the graph.

$$R\,(ti) \cap A\,(ti) = R\,(ti) \tag{5}$$

B. FAHP

Analytical hierarchy process (AHP) has been widely used to address multi-criterion decision making problems. It has been generally criticized because of the use of a discrete scale of one to nine which cannot handle the uncertainty and ambiguity present in deciding the priorities of different attributes.

The hierarchy of the decision variables is the subject of a pairwise comparison of the AHP. Traditionally, the pairwise comparison is established using a nine-point scale which converts the human preferences between available alternatives to numerical values that can denote equal importance, weak importance, strong importance, demonstrated importance and absolute importance. Even though the discrete scale of AHP has the advantages of simplicity and ease of use, it is not sufficient to take into account the uncertainty associated with the quantification of one's perception [11]. The linguistic assessment of human feelings and judgments are vague and it is not reasonable to represent it in terms of precise numbers. It feels more confident to give interval judgments than fixed value judgments. Hence, triangular fuzzy numbers were used to decide the priority of one decision variable over another. Synthetic extent analysis method was used to decide the final priority weights based on triangular fuzzy numbers.

Fuzzy set theory has proven advantages within vague, imprecise and uncertain contexts for it resembles human reasoning in its use of approximate information and uncertainty to generate decisions. It was specially designed to mathematically represent uncertainty and vagueness and provide formalized tools for dealing with the imprecision intrinsic to many decision problems. Fuzzy set theory handles classes and grouping of data with boundaries that are not sharply defined (i.e. fuzzy). Fuzzy set theory includes the fuzzy logic, fuzzy arithmetic, fuzzy mathematical programming, fuzzy graph theory and fuzzy data analysis. Usually, the term fuzzy logic is used to describe all of these.

The FAHP is the fuzzy extension of AHP to efficiently handle the fuzziness of the data involved in the decision of best worker productivity improvement. It is easier to understand and it can 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 by using the extent analysis method, the synthetic extent value of the pairwise comparison is calculated. Based on this approach, the weight vectors are decided and normalized, thus the normalized weight vectors will be determined. Based on the different weights of criteria and attributes, the final priority weights are decided.

In the analysis method of fuzzy AHP X={x1, x2….xn} is given to be an object set, and U={u1,u2….um} to be a goal set. According to Chang's extent analysis (1996), each object is considered and extent analysis for each goal, gi, is performed. Thus, m extent analysis values for each object can be obtained, as in (6).

$$M_{gi}^{1}, M_{gi}^{2}, \ldots\ldots M_{gi}^{m}, \mathrm{I}=1,2,\ldots\ldots,n \qquad (6)$$

Where all the M_{gi}^{j} (j = 1,2,…,*m*) are triangular fuzzy numbers (TFNS) whose parameters *a*, *b*, and *c* are of least possible value.

A TFN is represented as (*a,b,c*). Chang's extent analysis is outlined as follows:

Step 1. The value of fuzzy synthetic extent with respect to the i^{th} object is defined as

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \qquad (7)$$

To obtain (7), perform the fuzzy addition operation of m extent analysis values for a particular matrix such that

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} aj, \sum_{j=1}^{m} bj, \sum_{j=1}^{m} cj \right), i = 1,2,\ldots,n \qquad (8)$$

And, to obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1}$, perform the fuzzy addition operation of $M_{gi}^{j} (j = 1,2,\ldots m)$ values such that

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} ai, \sum_{i=1}^{n} bi, \sum_{i=1}^{n} ci \right) \qquad (9)$$

Then, compute the inverse of the vector in (4) such that

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} ci}, \frac{1}{\sum_{i=1}^{n} bi}, \frac{1}{\sum_{i=1}^{n} ai} \right) \qquad (10)$$

Step2. The degree of possibility of $M_2 = (a_2, b_2, c_2) \geq M_1 = (a_1, b_1, c_1)$ is defined as

$$\mathrm{V}(\mathrm{M2} \geq \mathrm{M1}) = \sup_{y \geq x} \left[\min\left(\mu_{m1}(x), \mu_{m2}(y) \right) \right] \qquad (11)$$

It can be equivalently expressed as follows:

$$\mathrm{V}(\mathrm{M}_2 \geq \mathrm{M}_1) = \mathrm{hgt}(\mathrm{M}_1 \cap \mathrm{M}_2) = \mu_{M2}(d) = \left\{ \begin{array}{cc} 1, & \text{if } \mathrm{b}_2 \geq \mathrm{b}_1 \\ 0, & \text{if } \mathrm{a}_1 \geq \mathrm{a}_2 \\ \dfrac{a_1 - c_2}{(b_2 - c_2) - (b_1 - a_1)}, & \text{otherwise} \end{array} \right\} \qquad (12)$$

Where, d is the ordinate of the highest intersection point D between μ_{m1} and μ_{m2}.

To compare M_1 and M_2, we need both values of V ($M_1 \geqq M_2$) and V ($M_2 \geqq M_1$), in Fig. 1.

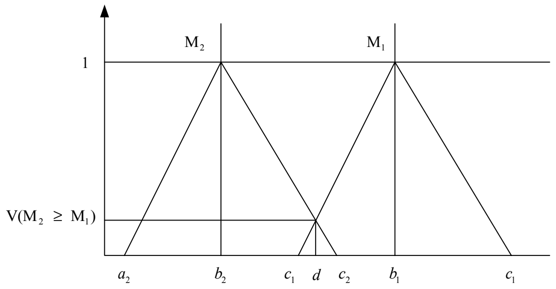

Fig. 1. The intersection between M_1 and M_2.

Step 3. The degree of possibility for a convex fuzzy number to be greater than k convey fuzzy number M_i (i = 1, 2, …, k) can be defined by

$$\mathrm{V}(\mathrm{M} \geqq \mathrm{M}_1, \mathrm{M}_2, \ldots \mathrm{M}_k) = \mathrm{V}[(\mathrm{M} \geqq \mathrm{M}_1) \text{ and } (\mathrm{M} \geqq \mathrm{M}_2) \text{ and} \ldots (\mathrm{M} \geqq \mathrm{M}_k)] = \min \mathrm{V}(\mathrm{M} \geqq \mathrm{M}_i),\ i = 1,2,3,\ldots.\mathrm{k}. \qquad (13)$$

Assume that

$$d'(A_i) = \min\ V\ (Si \geq S_k) \qquad (14)$$

For k=1,2,…..,n; $k \neq i$. Where A_i (i=1,2,…n) are n elements.

Then the weight vector is given by

$$W' = \left(d'(A_1), d'(A_2), \ldots\ldots d'(A_n) \right)^T \qquad (15)$$

Step 4. Obtain the normalized weight vectors through normalization (16).

$$W = \left(d(A_1), d(A_2), \ldots\ldots d(A_n) \right)^T \qquad (16)$$

Where, W is a non-fuzzy number.

III. RESULTS

The case study involves a manufacturing firm located in Chungli, Taiwan. Its major product line includes FCB and IC board. To identify the vital components of research according to the view of management and academic experts with five engineers were conducted using Delphi method in order to model the research components and valid framework through ISM.

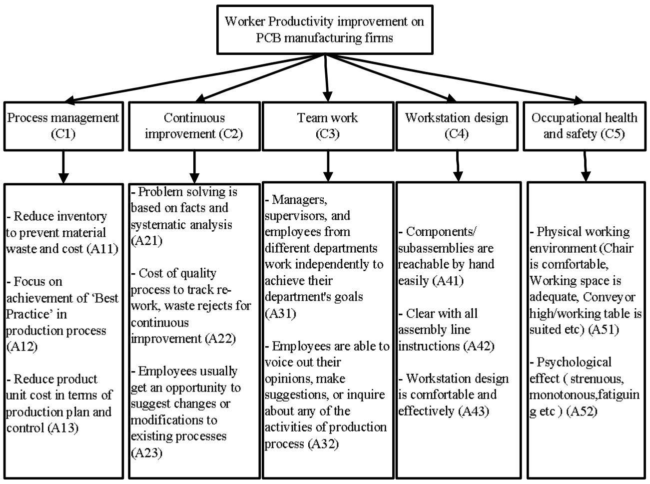

Fig. 2. Result of ISM for FAHP

The whole hierarchy of worker productivity can be easily visualized from Fig. 2. After the construction of the hierarchy, the different priority weights of each criteria and attributes were calculated using the FAHP approach. The comparison of the importance or preference of one criterion or attribute over another can be done with the help of the questionnaire. The preference of one measure over another is decided by available research, current business scenario and experience of the experts. The method of calculating priority weights of the different decision criteria using FAHP is discussed below.

The different values of fuzzy synthetic extend (10) with respect to the four different criteria are noted by M_1, M_2, M_3, M_4 and M_5.

$M_1 = (23.85, 16.76, 17.84) \otimes (1/36.73, 1/34.17, 1/60.71) = (0.678, 0.515, 0.301)$

$M_2 = (13.32, 6.99, 7.49) \otimes (1/36.73, 1/34.17, 1/60.71) = (0.379, 0.215, 0.127)$

$M_3 = (8.33, 1.55, 1.55) \otimes (1/36.73, 1/34.17, 1/60.71) = (0.237, 0.048, 0.026)$

$M_4 = (13.65, 7.27, 8.25) \otimes (1/36.73, 1/34.17, 1/60.71) = (0.389, 0.223, 0.139)$

$M_5 = (1.56, 1.6, 1.6) \otimes (1/36.73, 1/34.17, 1/60.71) = (0.044, 0.049, 0.027)$

The degree of possibility of M*i* over M*j* ($i \neq j$) can be determined by (12) and (13).

$V (M_1 \geq M_2) = 1$，$V (M_1 \geq M_3) = 1$，$V (M_1 \geq M_4) = 1$，$V (M_1 \geq M_5) = 1$

$V (M_2 \geq M_1) = 0.219$，$V (M_2 \geq M_3) = 0.039$，$V (M_2 \geq M_4) = 0.1$，$V (M_2 \geq M_5) = 1$

$V (M_3 \geq M_1) = 0.352$，$V (M_3 \geq M_2) = 0.189$，$V (M_3 \geq M_4) = 0.194$，$V (M_3 \geq M_5) = 0.11$

$V (M_4 \geq M_1) = 0.217$，$V (M_4 \geq M_2) = 1$，$V (M_4 \geq M_3) = 0.357$，$V (M_4 \geq M_5) = 1$

$V (M_5 \geq M_1) = 0.349$，$V (M_5 \geq M_2) = 0.189$，$V (M_5 \geq M_3) = 1$，$V (M_5 \geq M_4) = 0.193$

TABLE I.

EVALUATION OF THE ATTRIBUTES WITH RESPECT TO CRITERIA C1

C1	A11	A12	A13	W_{C1}
A11	(1, 1 , 1)	(7/9, 3/4, 5/6)	(2/3, 2/3, 3/4)	0.036
A12	(6/5, 4/3, 9/7)	(1, 1, 1)	(13/2, 13/2, 7)	0.849
A13	(4/3, 3/2, 3/2)	(1/7, 2/13, 2/13)	(1, 1, 1)	0.115

With the help of (14), the minimum degree of possibility can be stated as follows:

$m(C1) = \min V (M_1 \geq M_2, M_3, M_4) = \min (1,1) = 1$. Similarly, $m(C2) = 0.1$, $m(C3) = 0.11$, $m(C4) = 0.217$, $m(C5) = 0.189$. The weight vector is given as $Wo = (1, 0.1, 0.11, 0.217, 0.189)^T$ (15) and after the normalization process, the weight vector of overall objective with respect to decision criteria C1, C2, C3 and C4 is as follows (16): $Wo = (0.62, 0.06, 0.07, 0.13, 0.12)$. The complete result is shown in Table 2.

TABLE II.

INTEGRATED THE PRIORITY WEIGHTS OF CRITERIA AND ATTRIBUTES TO ACQUIRE GLOBAL PRIORITY

Criteria		Attributes		Global priority	Ranking
C1	0.619	A11	0.036	0.022	8
		A12	0.849	0.525	1
		A13	0.115	0.071	3
C2	0.062	A21	0.032	0.002	13
		A22	0.818	0.051	7
		A23	0.150	0.009	11
C3	0.068	A31	0.231	0.016	10
		A32	0.769	0.052	6
C4	0.134	A41	0.452	0.061	5
		A42	0.521	0.070	4
		A43	0.027	0.004	12
C5	0.117	A51	0.851	0.100	2
		A52	0.149	0.017	9

Now, the different attributes are separately compared under each of the criterion by following the same procedure as discussed above. The matrix eigenvalue must be normalized and the weight vector of each attribute must be obtained. The fuzzy evaluation matrices of attributes and the weight vectors of each attribute are shown and the fuzzy evaluation matrices of decision alternatives and corresponding weight vector of each alternative with respect to corresponding attributes are determined. Finally, the priority weights of each worker productivity improvement can be calculated by weights of the corresponding criteria.

IV. DISCUSSION AND CONCLUSION

The ISM developed in this study acts as a tool for top management to understand the variables of worker productivity improvement. The results are quite generic and are helpful for the top management to start addressing the roots of the worker productivity improvement problem although ISM is developed on the basis of perception of the experts of worker productivity improvement. The created model is not specific to any sector and specific model for any other sector may differ slightly from the model. This approach considers the variables where fruitful results, in terms of worker productivity improvement, can be achieved.

Fuzzy AHP of group decision making is used for the justification of worker productivity improvement. The existing FAHP methods are complex and difficult to apply to most large-sized real-world problems. A good and simple method which is conceptually easy to understand and practically capable of solving real-world problems is desirable.

Decisions are made today in increasingly complex environments. In more and more cases, the use of expert opinion is necessary and different value systems are to be taken into account among other things. In many of such decision-making settings, the theory of group decision making can be of use. A particularly helpful approach is the fuzzy group decision making. In general, many concepts, tool and techniques of artificial intelligence, in the field of knowledge representation and reasoning, can be used to improve human consistency and application of numerous models and tools in broadly perceived decision making and operations research.

In this study, the fuzzy set theory demonstrated to be an excellent tool to handle qualitative assessments about worker productivity improvement systems because it is efficient in qualitative forecasting whereas humans are hesitant in making quantitative predictions. In the last two decades, few fuzzy multi-attribute models justifying worker productivity improvement were developed. This research serves as an addition to those. It builds up the theoretical model of worker productivity improvement by setting priorities in clarifying, organizing and integrating terms and concepts relevant to worker productivity improvement in the firm's process. Best practice, unit cost reduction and physical working environment were determined to be the crucial sub-factors for worker productivity improvement.

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