Contractor Selection for Maintenance in Small and Medium Industries using Analytical Hierarchy Process

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Abstract— The research based on the fact that the investment of information technology is needed for supporting daily operation and maintenance management in commonly industries. Although many models with varieties optimization and techniques have been proposed, there are limited actions to be linked into the actual industrial maintenance process. This paper introduce Analytical Hierarchical Process (AHP) method to provide important maintenance decision strategy for Small and Medium Industries (SMIs). The method is suitable for maintenance decision based on multiple maintenance criteria's and their alternatives. In case study, the maintenance contractor's selection problem have been demonstrated and the best decision result using maintenance decision support been achieved. The goal of this paper is to illustrate on how SMIs can use AHP to aid maintenance decision in the production plant.

Keywords: ***analytic hierarchy process, maintenance decision support system, small and medium indutries***

I. Introduction

Small and Medium Industries (SMIs) are very important aspect for economic growth in developing countries [1]. Although they operate in a smaller scale, many counts of larger industries have making them an important support role for their business needs [2]. However, the lack of capital and less effective in carrying out the maintenance of production process are the main problems that appeared. In Malaysia, although the government given a lot of capital assistance, due to lack of information about effective industrial process, has made the production in SMIs still cannot reach the expectations [3]. In common, the SMIs just follow the maintenance advice from the contractors to perform maintenance activities. Surely, it will makes too much maintenance cost for those machines as they do not have their own maintenance team. Sometime, to overcome this problem, Information Technology (IT) is the best solution by mining historical data and predicts future maintenance strategies.

Recently, IT has growing rapidly in industrial process. Many models with varieties optimization and techniques have been proposed ([4], [5], [6]). However, there are limited actions to be linked into the actual industrial maintenance process [7].

In order to increase the effectiveness of the units, computerized system like Decision Support System (DSS) needed to simplify the analyzing process and to reduce the time needed for maintenance decision [8]. Analytic Hierarchy Process (AHP) is the model that used to obtain a model maintenance decision support in accordance with the problems that are often found in Small and Medium Industries (SMIs). In AHP, the goal or the decision that is suggested from any maintenance problem can be determined from selected alternatives. This AHP method has provided the operational maintenance decisions for SMIs.

II. AHP Methodology

AHP developed by [9] as mathematical decision making model to solve complex linear algebra problems when there are multiple objectives or criteria to be considered. It's requires the decision makers to provide judgments about the relative importance criterion for each decision alternatives [10]. AHP has been used to solve the problem of maintenance in industrial areas. For instance, [11] have used AHP to justify the Total Productive Maintenance (TPM) in Indian industries. While [12] have described the application of AHP to selecting the best maintenance strategies for an important Italian oil refinery. Moreover, reference [13] has been evaluated the information service quality of ten primary high tech industry information center web portals in China using AHP. Then, AHP also has been used to evaluate the call center service quality in Taiwan telecommunication industries by [14].

There are several steps to implement the AHP model [15]. The first step is describing the maintenance problem into an AHP decision hierarchy. The hierarchy can be visualized as a diagram in Fig. 1. It consists of an overall goal at the top, a group of options or alternatives for reaching the goal at the bottom, and a group of factors or criteria filling up at the middle, relate the alternatives to the goal. In most cases, the criteria and then divided into sub-criteria in some degree based on the needs of the problem. Clearly, the AHP is most efficient applied when the total number of criterions and alternatives is not excessive [9].

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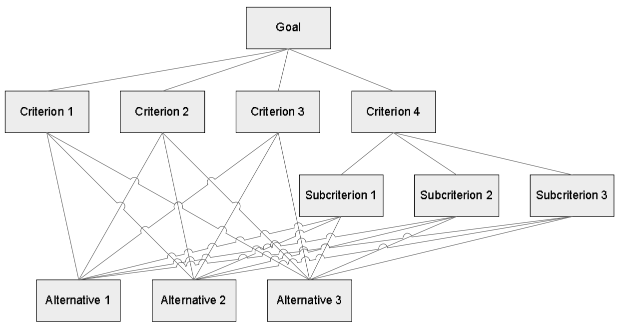

Figure 1: The AHP Hierarchy

The AHP concept establishes the priorities in each element in hierarchy by make a pairwise comparison of the criterions and alternatives in every level. The comparisons are predefined on one-to-nine ratio scale as listed in Table 1.

Table 1: Scale of the Importance

Intensity of Importance	Value Description	Explanation
1	Criteria i and j, are equal importance	Two activities contribute equally to the objective
3	Criteria i is weakly more important than j	Experience and judgment slightly favor one activity over another
5	Criteria i is strongly more important than j	Experience and judgment strongly favor one activity over another
7	Criteria i is very strongly more important than j	An activity is strongly favored and its dominance demonstrated in practice
9	Criteria i is absolutely more important than j	The evidence favoring one activity over another is the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent values. If criterion i has one of the above non-zero numbers assigned to it when compared with criterion j. then j has the reciprocal value when compared with i.	When a compromise in judgment is needed e. g. if i = 3, j = ⅓

The comparisons are made using the judgments of the factors based on data obtained in the SMIs or from the knowledge and experience of the maintenance persons, i.e. technicians, managers, or other experts in the maintenance department. There are many situations where the judgments are close or tied in measurement and the comparison must be made between one-to-nine ratio scales. For example there are comparisons to be made between 1 and 2, such as 1.1, 1.2, 1.3, …, 1.9.

The example of comparison formula is shown in the Formula 1 below. It is a square matrix with as many rows (and columns) as there are criteria connected to the goal. The numbers in this matrix express the intensity of dominance of the criterion in the column heading over the criteria in the row heading. In many research, the ratio scale have been used, the matrix is reciprocal which mean that the numbers, which are symmetric which respect to the diagonal, are inverses of one another, $a_{ij} = \frac{1}{a_{ji}}$. If one criterion is judged to be three times more important than the others, then the others is as important when compared like the first.

Criterion(C)	**C_1**	**C_2**	**C_j**	**…**	**C_n**	
C_1	a_{11}	$\mathbf{a_{12}}$	$\mathbf{a_{1j}}$	**…**	$\mathbf{a_{1n}}$	
C_2	$1/a_{12}$	a_{22}	$\mathbf{a_{2j}}$	**…**	$\mathbf{a_{2n}}$	
C_i	$1/a_{1j}$	$1/a_{2j}$	a_{ij}	**…**	$\mathbf{a_{in}}$	
…	…	…	…	…	…	
C_n	$1/a_{1n}$	$1/a_{2n}$	$1/a_{in}$	**…**	a_{nn}	(1)

In general, $\frac{n(n-1)}{2}$ comparisons are needed if n is the number of element being compared in the triangle above the diagonal of ones. These comparisons show in bolt variables in Formula 1.

Approximating the weight vector in the matrix A, with i row and j column, takes from illustrated below, where $w_i > 0$ for i = 1, …, n denotes the weight of objective i. The next step is the calculation of a list of the relative weights of the criteria under consideration. This requires normalization of each column j in A, such that $\sum_j a_{ij} = 1$.

Criterion	**Criterion_j**	
Criterion_1	Anorm_{i1}	
Criterion_2	Anorm_{i2}	
Criterion_i	Anorm_{ij}	
…	…	
Criterion_n	Anorm_{in}	(2)
Total	1	

For each row i in the resulting matrix above, the average value is computed by:

$$w_i = \frac{1}{n} * \sum_{i=1}^{n} a_{ij} \quad (3)$$

Where w_i is the weight of criterion i in the weight vector, $w = (w_1, w_2, \dots, w_n)$ recovered from matrix A, with n criteria, by finding a non-trivial solution to a set of n equation with n unknowns.

Finally, given a decision matrix, the final priorities, denoted by A^i_{AHP}, of the alternatives in term of all the criteria combined are determined:

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$$A^{i}_{AHP} = \sum_{j=1}^{n} a_{ij} w_j \text{ , for } i = 1, 2, 3, \ldots, m \quad (4)$$

III. Case Study

Maintenance strategies can be explained as a collection of maintenance operation that gives best effort to benefit with least cost. Each maintenance operation have specific scenario to be implemented to get the best result. In this research, the AHP has used to help decision makers to make proper evaluations and relatively accurate decisions. The example case in Fig. 2Figure shows the hierarchy framework of contractor selection in SMIs base on specific criterions and alternatives. In this research, the data are gathered from the interviewed and recorded data from one of SMI in Malaysia [16].

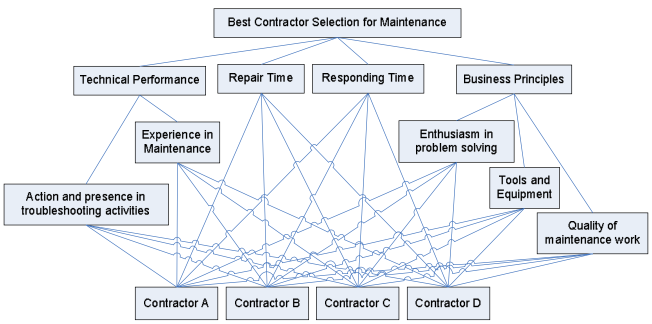


Figure 2: Contractors Selection

The hierarchy is used for conducting preliminary analysis in domain of contractor selection. Basically, the contractor requirement can be decomposed into several criterions and sub-criterions in different level of uncertainty and ambiguity. Analysis can be performed at each level independently, but linked and cumulated at the higher levels in the hierarchy. Decisions and judgments are made in each level of structure, and finally aggregated to produce decision in the top of hierarchy

In conducting pair wise comparisons between contractor selections, the decision makers sequentially compares two criterions and alternatives. From (1), in the criterions level, the system needs 6 pair wise comparisons input. In sub criterions, the system need 1 pair wise comparison for technical performance sub criterion and need 3 pair wise comparison for business principle sub-criterion. Moreover, 6 pair wise comparison are needed in alternatives level linked for every higher level in hierarchy. Base on our interviewed from SMI in [16], all of the pair wise comparison calculations have been inputted and generated.

For all pair wise comparisons, we construct pair wise comparison matrixes using (1). After complete, normalization matrix are produced by divided the number of matrix by their respective column using (2). Then to determine the priorities, we simply find the average of the various rows from normalization matrix using (3). The result shows in Table II for every criterions and sub-criterions, those are the priority evaluation weights of Technical Performance (TP), Business Principles (BP), Experience in Maintenance (EM), Action and Presence in Troubleshooting Activities (AP), Quality of Maintenance Work (QW), Tool and Equipment (TE), Enthusiasm in Problem Solving (EP), Repair Time (RT) and Response Time (RnT).

Finally, to get the overall ranking, the priority evaluation weights are multiplied in each table using (4). The data evaluations for four different contractors are summarized on column TOTAL in Table 2. The data shows the weight of every contractor C received the highest final ranking and it is selected is the best contractor for SMI.

As discussed, solving AHP problems can involve a large number of calculations. Therefore, the AHP program as Decision Support System (DSS) is applicable for critical decision support.

Table 2: Contractors Ranking with AHP

Best Contractor Selection Maintenance									TOTAL
Contractors	TP		BP			RT	RnT		
	EM	AP	QW	TE	EP				
A	0.074	0.030	0.007	0.009	0.011	0.047	0.068		**0.245**
B	0.049	0.044	0.010	0.013	0.027	0.083	0.058		**0.284**
C	0.099	0.059	0.014	0.004	0.005	0.081	0.041		**0.304**
D	0.025	0.015	0.003	0.017	0.011	0.049	0.047		**0.167**
TOTAL	0.247	0.148	0.034	0.043	0.053	0.260	0.214		**1.000**
	0.396		0.130						
	1.000								

IV. Implementation

From the previous sections, the conclusion have been reached that AHP program is needed as DSS in SMIs and it is still very limited action to implement those concept in the real industrial process. In this section, AHP DSS application development and implementation have been outlined. DSS at least must have required data in response to the maintenance event including breakdown machine, downtime history and all the parameters such as contractor selection. Furthermore, the system must have the capability to show the appropriate maintenance strategies and maintenance decision goal base on the data inputted. Hence, our system includes the following modules.

(i) Maintenance data input and calculation formula, to get the appropriate data input for decision making model used.

(ii) Analytic Hierarchy Process formula, to get an analysis for decision goal for each maintenance alternatives and criterions inputted

The program must be running some form of web server software such as Apache and Windows Server, and must have a continuous connection to the internet as shown in Fig. 3. The server must also have Hypertext Preprocessor (PHP) installed on it so that program will be able to work. All of the program files must be copied over into the web domain to function properly. For database, server must have MySQL database installed. All of the data can be uploaded in that database server. Once the installation is complete the site will be fully accessible from world wide web at the domain address that it is being hosted from anywhere.

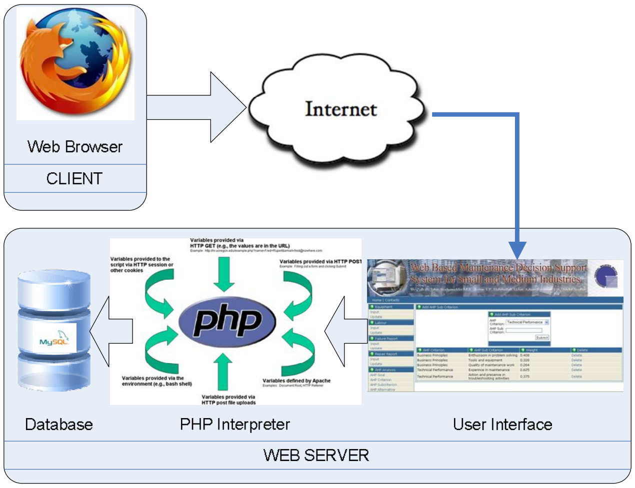


Figure 3: Web DSS Application Concept

Use case diagram for AHP development in DS tools are given in Fig. 4.

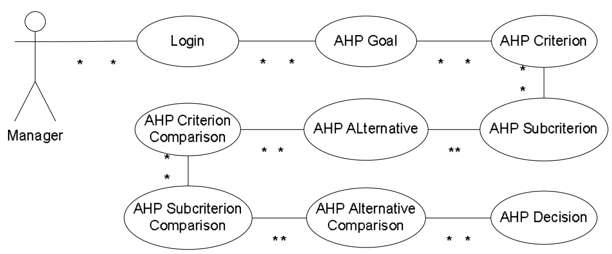
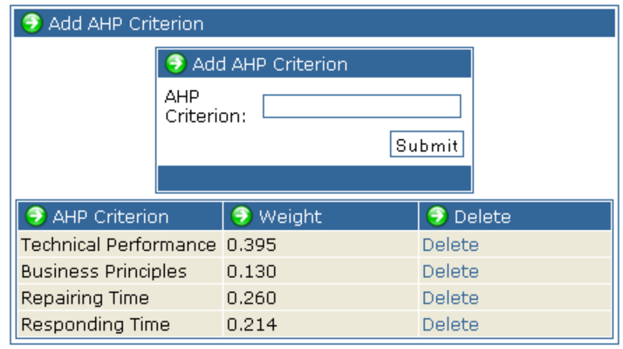


Figure 4: Use Case Diagram AHP

Several tools have been used to build the DSS applications. It is divided into hardware device and software device. We have developed DSS tools using AHP for evaluating SMI's contractors. For hardware, we use two Personal Computers (PC), those are Hewlett-Packard (HP) sw4400 Work Station Intel(R) Pentium(R) D CPU 3.40 GHz 1GB of RAM and Monitor HP L1506 and MIMOS Intel(R) Pentium(R) 4 CPU 2.80 GHz, 248 MB of RAM and Monitor MIMOS. The first PC is for the server and the other for the testing in client side. Microsoft Windows XP Professional Version 2002 Service Pack 2 has been used as Operating System (OS). To develop PHP code, Macromedia Dreamweaver version 8 has been used. Apache distribution containing MySQL and PHP using XAMPP WIN 32 version 1.4.15 are used as web server include User Interface (UI), PHP interpreter and database.

Every step in AHP is provided in our DSS application design using use case AHP diagram shows in 5. It is provides the scenarios that convey how the system should interact with the end user (maintenance person) or another system to achieve a goal. This use cases describe the behavior of software or systems and simply show the steps that a user follows to perform a task. The use case AHP also explains about the scenario using AHP to get the best goal from multiple alternatives and multiple criteria. The decision maker should be an authorized to execute the next process in sequent from AHP goal until AHP decision. In this AHP analysis, the best goal can be achieved from all alternatives that have been inputted.

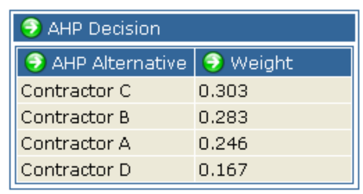
One of our user interface is shown in Fig. 5. The program designed into a display screen with a user can interact using a computer input devices such as keyboard and mouse.



AHP Criterion	Weight	Delete
Technical Performance	0.395	Delete
Business Principles	0.130	Delete
Repairing Time	0.260	Delete
Responding Time	0.214	Delete

Figure 5: Maintenance DSS Output Interface

For testing, we use the Expert Choice Software to verify and validate our program. It shows similar results in Expert Choice software, compared to our DSS. Our experimental result using AHP method in our program is given in Fig. 6.



AHP Alternative	Weight
Contractor C	0.303
Contractor B	0.283
Contractor A	0.246
Contractor D	0.167

Figure 6: AHP Decision Result

In addition, our system is better because it is able to keep the data in the database and able to recall the information whenever necessary. Moreover, this web based DSS can simplify and reduce the data acquisition time compared to stand alone expert choice software or the currently used paper-based reporting system. This system also provided the maintenance plan with the application for analysis and decision support that often ignored by many proposed computerized base maintenance managements for industries.

V. Conclusion

The research based on the fact that the investment of computerized system is needed for supporting daily operation and maintenance management in commonly industries. An AHP model has been proposed to obtain a model of maintenance DSS in accordance with the problems that are often found in SMIs. This AHP method has provided the operational maintenance decisions for SMIs. The example case has been given on the contractor selection base on the specific criterions and alternatives gathered from the interviewed and the recorded data from one of SMI in Malaysia and have been given the desired results.

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In future work, it is required further analysis of the problems so this system can be used for another maintenance problem in the SMIs. Next, the analysis is also carried out with the implementation of the DSS programs and has inspired us to update the AHP model program with the addition of intelligent logic and the suitability of algorithms concept.

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