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Article

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Appling the Analytic Hierarchy Process as the Risk Evaluation Model to Improve Hospital Biomedical Waste Disposal Outsourcing Quality

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Improvement of medical quality has become a trend in hospital development. In recent years, environmental protection has become a rising issue in Taiwan, and people have begun to discuss the biomedical waste that comes from hospitals. According to an estimate in "To Err is Human," published by Institute of Medicine, the economic loss resulting from medical malpractice is about $17 to $29 billion, and the question of whether biomedical waste is properly disposed of is included as an incident of medical malpractice. Therefore, this study aimed to study use risk evaluation in order to screen out evaluation factors. Subsequently, the Analytic Hierarchy Process was employed to determine the weight of each factor. The results of the study provide hospitals with biomedical outsourcing critical risk factor criteria and their order by importance and can be provided to hospitals as reference for the management of biomedical waste disposal outsourcing.

Keywords: Analytic Hierarchy Process (AHP), biomedical waste, waste management, outsource, medical wastes

After Taiwan launched National Health Insurance (NHI), in order to encourage patient visits, hospitals have been improving its quality on medical service. Thus, not only the disposable medical materials are widely used but also the amounts of medical wastes are increasing. To effectively manage medical wastes, hospitals have been outsourcing the disposal works to private service providers, who have been legally established with approvals from governmental authorities, in order to remove and clear those wastes.

For the recent global budgets ceiling and care management in Taiwan, both the hospitals and NHI institute are facing financial crisis. To meet the two ends of patients care quality and operational revenues reduction, the managements are seeking to outsource some parts of non-mainstream works. Thus, the outsourcing can reduce cost and improve productivity. Yang et al. and Roberts suggested that since hospitals and health care systems are facing financial problems due to budget ceiling, managers are outsourcing non-core

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businesses and works, including biomedical wastes disposal, to other service providers so that they strike a balance between difficulties of patient care quality and of hospital' s operational revenue reduction [1, 2]. Therefore, it is found that Taiwan hospital waste disposal are gradually being taken over by service providers from private sectors.

Most hospitals currently do not accept to process and remove hazardous biomedical wastes on their own. Most hospitals hire government-approved waste management facilities, either private or public, to help remove or process the wastes [3]. Taiwan' s Waste Disposal Act stated that organizations who produce medical wastes shall either pay commission to waste disposal organizations, either public or private, or on their own to remove and dispose the wastes. Therefore, the cost of disposal is inevitable.

According to the recent statistics of medical information from the Ministry of Health and Welfare, Executive Yuan, from 2010 to 2015, approximately 20,000 healthcare facilities (HCFs) or hospitals in an average produced about 120,000 tons of medical wastes per year in Taiwan. Regular wastes were reported to be 76% of total, whereas the rest of the harmful biomedical wastes accounts for about 30,000 tons (25%) [4]. However, another article showed the different composition with the medical wastes in the HCFs, there are general waste (48%), medical waste (39%) and sharps (13%) [5]. In Iran, an inventory of all 58 healthcare facilities in the province of Isfahan was performed and the results were analyzed using statistical procedures. The results indicated that 36.2%, 4.6%, and 59.2% of total wastes produced were infectious, sharp, and general wastes, respectively [6]. So, maybe it is the main source of waste among the healthcare industry in Taiwan. Hsiao et al. investigated regional and higher hospitals' method of infectious wastes disposal and found that 62.5% public hospitals, 80% and 75.8% private hospitals are hiring disposal and clearance organizations to handle the wastes [7]. Also, Chen et al. investigated the outsourcing works of the general matters departments of Taiwan' s regional and higher hospital and found that, regardless of hospitals' operational and production structures, waste disposal is one of the works that has higher frequency of outsourcing [8].

Mathur et al. provide the waste produced in the course of healthcare activities carries a higher potential for infection and injury than any other type of waste. Inadequate and inappropriate knowledge of handling of healthcare waste may have serious health consequences and a significant impact on the environment as

well [9]. Lin provide after controlling for the quantity of each contact to the medical infectious wastes and the usage of glove protection, the result of multivariate analysis showed that there were dose-response relationship between hour of weekly contact with the infectious medical wastes and skin symptoms of reddish, itching, rash or blisters, and skin dry or cracking. Also, hour of weekly contact was also associated with contact dermatitis. In addition, after controlling for the quantity of each contact, there was also a dose-response relationship between hour of weekly contact and soreness or reddish swollen of the eye [10].

Taiwan has very strict regulations on management of medical disposals. Those who violate stipulations will be fined and demanded to improve, and any revelation of information regarding said violation will cause depreciation of commercial reputation of the hospitals. From the above mentioned documents, it is found that most Taiwan’ s hospitals are outsourcing works of medical wastes disposal to specialized companies. However the question on how hospitals decide a proper company to undertake such works is a question of multiple criteria. Therefore, how hospitals making choices on an ideal medical disposal company through an objective selection mechanism/model is especially critical.

To conclude, this study attempts to construct a selection of model for evaluating candidate wastes disposal organizations in an approach of analyzing the commission risks of medical wastes disposal. First, the hospitals assign its waste managerial personnel’ s as the experts. Then, Liao & Ho evaluation factors are obtained by using the Failure Mode and Effect Analysis (FMEA) method in the study [11]. Next, by applying Analytic Hierarchy Process, the hierarchical structure for commission evaluation and the weighted computation for the waste disposal companies are built. Last but not least, the research results from the study are available for decision makers and managers to take reference so that they are more aware of the risk evaluation items when they select the waste disposal companies so as to ensure not to violate relevant rules and regulations and to improve the health care quality.

MATERIALS AND METHODS

In the first part of the study, Liao & Ho evaluation factors are obtained by using the Failure Mode and Effect Analysis (FMEA) method in the study [9]. The importance of the risk assessment of biological medical wastes is obtained and the importance of the ranking (see Table 1), 16 criterion are used in this study, take its PRN in more than 40 (excluding 40) , and the criteria for classification, will be classified as a criteria for

the item, and the original evaluation of the project is a standard. In the next part, by applying AHP we construct an evaluation model for selecting companies that mentioned. Detail descriptions of the research methodology are as follows.

Item	Evaluation Criterion	RPN
1	Provides clearly marked sharp instrument receptacles	100
2	Removal frequency	100
3	Vehicular equipment complies with Laws and ordinances	100
4	Singular processing speed	100
5	Offers freeze-storage equipment	90
6	Handling capacity	90
7	Handling method	80
8	Vehicular dispatch capability	64
9	Emergency management plans	60
10	Offers equipment maintenance	56
11	Alternate firm scope	50
12	Disposal permit time	48
13	Supplies a clearly marked biomedical waste container	40
14	Classification weighing	40
15	Offers vehicular travel route information	40
16	Creates a storage location plan	20

Extract：Liao C, Ho CC, (2014) Risk management for outsourcing biomedical waste disposal－Using the failure mode and effects analysis. Waste management 34(7): 1324-1329.

Table 1. Evaluation Factors obtained using FMEA Risk Assessment

-Analytic Hierarchy Process (AHP)

AHP can simplify a complicated question and solve it hierarchically with different perspective. Also, by its quantitative judgment and comprehensive evaluation through its context, it provides decision makers with sufficient information to make suitable decision as well as reduce the risk of making wrongful decisions. In the decision-making methodology of multiple targets and guidance, AHP is a simple and feasible method [12]. Plus, AHP is mainly used in situations of uncertainties where one needs to make decision based on multiple evaluation guidance [13]. By collecting expert' s opinions and systemizing complex evaluation questions, AHP pairs and compares factors in each hierarchy by nominal scales and constructs comparison matrices and after quantification. Further, by obtaining an eigenvector and an eigenvalue, one can assess

the level of consistency of the comparison matrices so to provide a reference for decision maker' s judgment. In this study, AHP is consisted of following steps:

Building Hierarchical Structure

When cope with complex questions, it can be decomposed by hierarchical structure. Based on a hypothesis that a man cannot compare 7 and more things in a given time, number of factors in each hierarchy does not exceed 7. Under such condition, one can compare more rationally meanwhile ensure the consistency [10 11]. The first hierarchy is the goal researchers are looking for, whereas the bottom hierarchy is the solution options (or replacing options), and between which there are factors and conditions to be evaluated.

-Calculation of various factorial weights in each hierarchy

1) Building pair wise comparison matrix among factors

Having previous hierarchy' s factors as evaluation basis, the factors in a given hierarchy compares in pair wise among the factors. If there is *n* factors, there should be *n(n-1)/2* pair wise comparison. Setting $C_1, C_2, \ldots, Cn$ as a set of factors, the quantification judgment for pair wise factor C_i, C_j can be shown as matrix *A* of *n* by *n*.

$$A = [a_{ij}] = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \end{array} \quad \ldots\ldots (1)$$

The comparing results of n factors are placed as the upper triangle in the comparison matrix (the main diagonal is comparison of factors themselves and therefore be 1). And the values of lower triangle are the inverse of its each relative value in upper triangle, i.e. $a_{ij} = 1/a_{ij}$. When $a_{ij} = 1$ and $a_{ij} = 1/a_{ij}$, $i, j,.. = 1, 2,\ldots,n$, a quantified relative importance judgment can be provided to paired two factors (C_i, C_j). In matrix *A*, values are demonstrated by a_{ij} whereas $W_1, W_2, \ldots, W_n$ demonstrates number of n factors, and $C_1, C_2, \ldots, C_n$ are weights in quantification which shows the reported judgment values. The relationship between weight W_i and a_{ij} can be shown as $W_i / W_j = a_{ij}$ (for $i, j, = 1,2,\ldots,n$) and the matrix *A* is:

$$A = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \end{array} \quad \text{..... (2)}$$

2) *Calculation of eigenvector and an eigenvalue*

After getting pairwise comparison matrix, weight of factors of each hierarchy can be achieved. Pairwise comparison matrix *A* multiplies factor weight vector *x* equals to *nx*, that is $(A - nI)x = 0$ At this time, *x* is called eigenvector. Because a_{ij} is evaluated by subjective judgment of the decision maker during pairwise comparison, there is some discrepancy at certain level with real W_i / W_j value, so $Ax = nx$ is unable to be feasible. Saaty suggests replacing *n* by matrix' s maximal eigenvalue λ_{max} of *A* matrix [14], namely

$$\lambda_{\max} = \sum_{j=1}^{n} a_{ij} \times \frac{W_j}{Wi} \quad \text{..... (3)}$$

if *A* is a consistency matrix, eigenvector *x* can be calculated by following formula

$$(A - \lambda_{\max} I)x = 0 \quad \text{..... (4)}$$

3) Consistence Index

Saaty suggested to examine by Consistency Index (CI) and Consistency Ratio (CR). The formulas are as follows [12]:

$$CI = (\lambda_{\max} - n)/(n-1) \quad \text{..... (5)}$$

$$CR = CI / RI \quad \text{..... (6)}$$

where the RI is random index (see table 2), which relates to number of compared values, randomly produced from CI of pair wise comparison matrix. When $CR \le 0.1$, the consistence of the matrix is reached.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 2. Random Index (RI) Table

Weighted calculation of entire hierarchy

After weighted calculation in factors of each hierarchy, one can compile the weighted calculation of entire hierarchy in order to decide the ultimate solution option.

Analysis Tools

Microsoft Excel 2007 is the tool for data processing and analysis.

RESULTS

Model Building and Application

The evaluation model construction in this study the weight of each factor was analyzed using AHP method, includes 6 steps. By applying AHP one can decide the weight in each evaluation criterion and make order of replacement options in order to sort out the best option. The construction and results are as follows:

Applying AHP to decide the weight of each risk evaluation criterion in deciding medical waste disposal outsourcing

Step one: building a hierarchical structure

Decompose the evaluation questions into decision factors such as goal, criterion, sub-criterion, and optional solutions, as shown in Table 3.

Step two: Building the pair wise comparison matrix for the factors

The criteria' weights provided by the experts are collected and calculated to yield their geometric means as the integrated scores, which are the weights for medical waste disposal companies selection criterion. Taking "primary criterion" as example, the pairwise comparison matrix from formula (1) and (2) is shown in Table 4 and 5.

Step three: Calculation of Eigenvalues and Eigenvectors

Calculate the pair wise comparison matrixes of primary criteria and sub-criteria via eigenvector formula, i.e. formula (3) and (4), to yield the weight values in each hierarchy, as shown in Table 6.

Step four: Test of Homogeneity

The homogeneity of pairwise comparison matrix is calculated from formula (5) and (6) and is shown in Table

Goal	Criterion	Sub-criterion	Evaluation Solution
Biomedical Waste Disposal Outsourcing Risks Evaluation	Company's Qualification	Disposal permit time	A Company B Company C Company D Company
		Singular processing speed	
		Emergency management plans	
	Company's Equipment	Handling capacity	
		Handling method	
		Vehicular equipment complies with Laws and ordinances	
	Service capability	Offers freeze-storage equipment	
		Offers equipment maintenance	
		Provides clearly marked sharp instrument receptacles	
	Matching degree	Alternate firm scope	
		Removal frequency	
		Vehicular dispatch capability	

Table 3. Hierarchy Structure for Biomedical Waste Disposal Outsourcing Risks Criteria

	Company's Qualification	Company's Equipment	Services	Matching degree
Company's Qualification	1	1.02	0.86	0.87
Company's Equipment	0.98	1	0.86	0.90
Service capability	1.16	1.16	1	1.19
Matching degree	1.15	1.11	0.84	1

Table 4. Comprehensive Pairwise Comparison Matrix for Primary Criteria

3. There are total of 8 chief managers and task takers in the 4 hospitals. The CR and CR of comprehensive opinion are less than 0.1, and such result is in line with the rule of homogeneity.

Step five: Calculation of relative weight in respective hierarchy

The relative weights in respective hierarchy are shown in Table 6. We found that in the collective criterion from the hospitals experts, the most important criterion is the given companies' "Service capability (0.281)," follow by "Matching degree (0.253), and then companies "Qualification and Equipment (0.233). "For follow ups, the results of sub-criterion are as below.

Criterion	Sub-criterion	Sub-criterion weight	Test value
Company's Qualification	Disposal permit time	0.197	λ_{max}=3 CI=0.000 CR=0.000
	Singular processing speed	0.599	
	Emergency management plans	0.204	
Company's Equipment	Handling capacity	0.353	λ_{max}=3 CI=0.000 CR=0.000
	Handling method	0.324	
	Vehicular equipment complies with Laws and ordinances	0.324	
Service capability	Offers freeze-storage equipment	0.501	λ_{max}=3.060 CI=0.030 CR=0.051
	Offers equipment maintenance	0.204	
	Provides clearly marked sharp instrument receptacles	0.295	
Matching degree	Alternate firm scope	0.322	λ_{max}=3.001 CI=0.000 CR=0.001
	Removal frequency	0.349	
	Vehicular dispatch capability	0.329	

Table 5. Hierarchy Weight Analysis of the Evaluation Indicators

1. Hospitals consider Offers freeze-storage equipment (0.501) is the most important sub-criterion in the "Service capability". The second and third are, respectively, availability of provides clearly marked sharp instrument receptacles (0.295) and Offers equipment maintenance (0.204). Some wastes like needles are highly dangerous. Availability of specialized container for those wastes becomes a basic requirement, whereas Offers freeze-storage equipment system and its repairmen can provide better services to hospitals' management and that hospitals can avoid violating pertinent regulations.
2. Hospitals consider the Matching degree as the second most important criterion, and within which the removal frequency (0.349) is the most critical sub-criterion. Mainly because of the companies slow action in removing the waste, which may cause accumulation in the hospitals and thus the time expires for such storage. The second and third sub-criteria are Vehicular dispatch capability (0.329)

Level 2 Criteria	Weigh t	S	Level 3 Sub-Criteria	Sub-Criteria Weights	S
Company's Qualification	0.233	3	Disposal permit time	0.046	12
			Singular processing speed	0.140	2
			Emergency management plans	0.048	11
Company's Equipment	0.233	3	Handling capacity	0.082	6
			Handling method	0.075	8
			Vehicular equipment complies with Laws and ordinances	0.075	8
Service capability	0.281	1	Offers freeze-storage equipment	0.141	1
			Offers equipment maintenance	0.057	10
			Provides clearly marked sharp instrument receptacles	0.083	4
Matching degree	0.253	2	Alternate firm scope	0.082	6
			Removal frequency	0.088	3
			Vehicular dispatch capability	0.083	4

Table 6. Hierarchy Structure for Biomedical Waste Disposal Outsourcing Risks Criteria

and substitute Alternate firm scope (0.322), which are the factors to determine if companies are able to be cooperative so that the hospitals can avoid violating pertinent regulations.

3. In terms of the qualification of the companies, the Singular processing speed (0.599) is the most important sub-standard. Due to the delivery, manifest are evidence in showing whether such wastes are produced in both legal and proper course, the shorter period of time in obtaining such delivery the more effective the manifest prove that the production of waste is within the provisions of the law. However, the "Emergency management plans (0.204)" is not as stressed as "Disposal permit time (0.197)".
4. Companies' equipment and qualifications are important criteria. In the criterion of companies' equipment, the sub-criterion Handling capacity (0.353) are over Handling method (0.324), availability and Vehicular equipment complies with Laws and ordinances (0.324). These three criteria are correlated, so we can find that hospitals' criterion in commissioning risk evaluation is related to the governmental regulations.

Step six: entire hierarchical weight calculation produces the optimal disposal company

From the entire evaluation, hospitals primarily care about Offers freeze-storage equipment. Therefore, in time when hospitals are to decide for biomedical waste outsourcing, whether a given company can provide Offers freeze-storage equipment becomes an important factor in selecting an ideal candidate company. Normally, when it comes to outsourcing, hospitals assign all parts of a specific work, such as medical waste disposal, to a given company. However, when the wastes are centralized in collection, a hospitals wishes the commissioned company is able to provide relevant equipment to hospitals, even though the wastes are not yet removed from hospitals' premises.

Based on the company's qualification and current disposal loading, hospital managerial staff and tasks taker of a chosen hospital score 4 companies in this study, namely having only one hospital for further case study.

The chosen hospital applied the model provided in this study to evaluate the selection project as a whole and to make an order of the options based on preference. The one scored in the first place becomes the most ideal medical waste disposal company in this study. The scores and order are Company A (0.287) > Company B (0.263) > Company D (0.231) > Company C (0.220) . According to the result of this case study, Company A is the most ideal waste disposal candidate company, as shown in Table 7.

DISCUSSION

In recent years, because of the national health insurance payment was low in Taiwan and competition among hospitals has become increasingly intense. Following such a competitive trend, hospitals need to provide high quality and low-cost services to keep operating. When hospitals evaluate a given biomedical waste disposal vendor, their decisions are based mostly on experience and price. Therefore, this study sought to construct a practical and objective evaluation model to solve the risk of hospital biomedical waste disposal. The study results will hopefully become a basis of reference for hospital managers' evaluations in the future.

Recent research report, application APH model to analysis of waste, including olive mill solid waste management in Jordan and using Multi-criteria Decision Analysis (MCDA) from APH to deal with Municipal

Criteria	Weight	A Com.	B Com.	C Com.	D Com.
Disposal permit time	0.046	0.257	0.295	0.178	0.270
Singular processing speed	0.140	0.316	0.244	0.231	0.209
Emergency management plans	0.047	0.236	0.277	0.178	0.310
Handling capacity	0.082	0.306	0.267	0.228	0.198
Handling method	0.075	0.285	0.227	0.198	0.289
Vehicular equipment complies with Laws and ordinances	0.075	0.254	0.270	0.181	0.294
Offers freeze-storage equipment	0.141	0.297	0.283	0.205	0.215
Offers equipment maintenance	0.057	0.315	0.268	0.225	0.192
Provides clearly marked sharp instrument receptacles	0.083	0.282	0.228	0.335	0.155
Alternate firm scope	0.082	0.295	0.249	0.226	0.230
Removal frequency	0.088	0.236	0.291	0.186	0.287
Vehicular dispatch capability	0.083	0.313	0.268	0.228	0.192
Result	Total	0.287	0.263	0.220	0.231
	Sort	1	2	4	3

Table 7. Decision made by Subject Hospital in the Case Study which Applies AHP Model to Select Medical Waste Disposal Outsourced Company

Solid Waste Management (MSWM) [15 16]. However, there was no more related study using APH model to analyze medical or biomedical waste. According to our results, we offer the following four important contributions:

1. This study indicates the rule of establishing biomedical waste disposal.
2. This study specifies the weight on choosing each company.
3. We provided model for hospitals in evaluating biomedical waste disposal companies.
4. It is able to select the best biomedical waste disposal company efficiently.

CONCLUSION

The process for a hospital to select a waste disposal company is very complicated. Especially when there are no effective risk evaluation methodologies available in hospital management, the decision makers in the hospitals normally make decisions based on their own prior experience. Therefore, quantification of the evaluation mechanism by applying suitable tolls and method can further lead to finding a waste disposal company with reduced outsourcing risk. This study applied AHP to decide the weights of the criteria and to

construct the selection model. The result shows that hospital' s most emphasized criteria are, in order of, service capability, Matching degree, Companies' qualification and companies' equipment. Since the Waste Disposal Act provides that in event where commissioned company is in violation of pertinent regulations, the commissioner will be liable jointly for the penalty. This explains why the criteria of service capability and matching degree rank prior to the other two. Hospitals apply the actual evaluation data of selected waste disposal outsourcing risks in the structure provided in this study. The company who received highest score becomes the most ideal candidate. In reality, a given hospital in northern Taiwan is chosen for this case study. By applying AHP to construct a model, when facing problems of multiple criteria, hospitals' decision makers are able to select an ideal company of reduced waste disposal risks by a systematic methodology.

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