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Airport Ground Handling Services Equipment Purchase Decision Model with AHP Weighted

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 doi:10.20944/preprints202012.0799.v1

Abstract

The airport ground handling services (AGHS) equipment supplier selection problem involves a safety guarantee on the part of the AGHS company that carries out the daily work. AGHS company can prevent aircraft damage and delays in airlines schedules, and ensure reliable and high-quality ground handling service. In our research, we developed an AGHS equipment supplier selection model based on the analytic hierarchy process and an AHP weighted fuzzy linear programming approach, and we solved the AGHS equipment supplier's selection problem. The main objective of this article is to create an AHP and AHP-FLP decision model in order to help the AGHS company authorities select the best AGHS equipment supplier. The practical application in AGHS equipment supplier selection decisions can be interpreted as demonstrating that the proposed model provides knowledge and practical value for the AGHS industry.

Key words: Airport ground handling services, equipment purchase decision, AHP weighted,Membership function, fuzzy linear programming.

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1. Introduction

An airport ground handling service (AGHS) company is to handles diverse ground handling activities. We can distinguish two major types of ground handling work procedures that are designated as either terminal or airside operations. In this paper, we focus on how to obtain the best AGHS equipment suppliers and overcome airside operations. Ramp handling, as a major part of an AGHS company, encompasses the activities of loading and unloading airplanes as well as the transporting of passengers, crew numbers, baggage, freight items and mail between airplanes and terminal buildings. Ramp handling can be classified as an AGHS logistics service. This AGHS logistics service is provided by a third party ground handler (the AGHS company), the airline (self-handling) or by the ramp handling business unit of an airport [1, 2].

The task is even tougher for ground handlers whose work safety relies on technologically advanced AGHS equipment suppliers. In fact, most of the AGHS companies are concerned with the AGHS equipment supplier's manufactured performance and quality. In addition, AGHS company that purchases department managers who select good reputation equipment suppliers have two reasons to ensure that the airport's ground handling works safely. One reason is that the use of high-quality AGHS equipment can make ground handling work safer. The second is to obtain reliable assurances regarding high-quality ground handling service for airlines and airlines who pay for the ground handling service. However, the AGHS equipment supplier selection problem has a significant impact on ground handling service quality for the AGHS company. On the one hand, AGHS equipment supplier selection is affected by several important factors. Selection factors include the supplier's manufactured performance, the reputation in the industry, and the quality and the price [3]. MCDM techniques support the decision makers (DMs) in evaluating a set of

 doi:10.20944/preprints202012.0799.v1

alternatives. Depending on the purchasing situations, certain criteria have varying importance levels and there is a need to weigh the criteria [4,5]. On the other hand, selecting the best AGHS equipment supplier selection is a multi-criteria decision making (MCDM) problem [6]. The AGHS equipment supplier selection process plays an important role in the decision making of an AGHS company; selecting the best AGHS equipment supplier has become a time-consuming and complex process requiring professional knowledge and past experience, and the selection process can be a complicated job for AGHS company purchasing managers. The authors suggested a correct and effective selection method, in which the decision maker needs information and data to be analyzed and needs many factors to be considered [7]. The next section provides a review of the relevant literature.

2. Literature review

General supplier selection is discussed widely in the literature. For example, Monczka et al. [8] suggested assessing the value of suppliers using factor analysis. Vonderembse and Tracey [9] investigated 268 purchasing managers to determine individual supplier selection criteria from suppliers involving in-product development activities and continuous improvement efforts, Thus, suppliers learn about customer requirements, culture, and decision making patterns that help them to adjust and apply their resources. In those ways, equipment suppliers see the greatest benefit. This is because they understand the customer’s real need. Bhutta and Huq [10] highlighted two main approaches (the total cost of ownership and the analytical hierarchy process) that managers can use to make effective decisions regarding supplier selection. Sarkis and Talluri [11] applied the analytic network process (ANP) model to strategic supplier selection. Çebi and Bayraktar [12] integrated lexicographic goal programming (LGP) and the analytic hierarchy process (AHP) model was proposed for selecting suppliers.

Perçin [13] pointed out that the integrated AHP model and multi-objective pre-emptive goal programming (PGP) model can be useful to all firms for their supplier selection decisions. Ramanathan [14] proposed a data envelopment analysis (DEA) methodology to integrate the total cost of ownership (TCO) and the AHP approaches for selecting appropriate suppliers for a firm.

Although the AGHS equipment supplier evaluation problem plays an important role in an AGHS company, the publications on this subject are lacking. To date, some research studies are valuable for evaluating an equipment supplier. For example, Sevkli et al. [3] conducted a hybrid method (e.g., AHP-fuzzy linear programming (FLP) approach to solving the supplier selection problems of a Turkish appliance manufacturer. This study addressed one of the most important subjects in supplier management, providing a better decision making process for supplier selection using appropriate quantitative techniques. The study has a number of managerial implications. First, for actual industry applications, supplier selection criteria that may contain quality evaluation, price, delivery, capacity, and flexibility cannot be quantitatively and precisely measured using traditional decision making methods, such as crisp AHP. To overcome this drawback, fuzzy numbers that enable one to capture a decision maker's subjective assessment regarding supplier selection criteria and to provide accurate supplier selection decisions. Second, the crisp AHP method is implemented under non-restricted situations in selecting the best supplier. The buyer company's purchasing managers realize that their suppliers have a major effect on customers' satisfaction levels. Therefore, they should not make their supplier selection decisions based only on the price and reputation, which was essentially the case under the traditional AHP method. In other words, the buyer company can only succeed by implementing the optimum supplier selection method in terms of more efficiently responding to uncertainty and resource constraints. In an actual situation for an equipment supplier selection problem, at the time of decision making, the value of many criteria and constraints are presented with unclear conditions, such as " very high in quality" or "low in price" Deterministic models cannot easily take this vagueness into account. In this regard, the AHP-FLP method would prove to be more useful than traditional AHP methods [5].

Nevertheless, relatively little work has been undertaken on rationalizing the real practice regarding AGHS equipment supplier selection applications of the supplier selection methods. To rectify this imbalance, this paper applies an integrated method of AGHS equipment supplier selection, an weighted fuzzy linear model (AHP-FLP) to a Taiwan AGHS company. The above-mentioned value research offers a signpost and our main goal is to help AGHS companies' purchasing managers adopt simple systematic methods to evaluate an optimal equipment supplier. To address these issues, this integrated application model has very valuable references for equipment suppliers or buyers (e.g., AGHS company).

The rest of this paper is structured as follows: Section 2 briefly describes the proposed methods, In Section 3, the proposed integrated application model for airport ground handling equipment supplier selection problems are described in detail. In Section 4, we use the AHP-FLP approach to solve the AGHS equipment supplier selection problems. We explain how the proposed approach is used in a real world example. In Section 5, our conclusion is discussed.

3. Methods

In this paper, we introduced the following two different methods, the AHP method and the AHP-FLP model, solving the AGHS equipment supplier's selection problem.

3.1 The AHP method

The AHP method is a decision-support procedure developed by Saaty [15] for dealing with complex, unstructured and multiple-criteria decisions. AHP is based on three concepts: the structure of the model, a comparative judgment of the alternatives criteria and synthesis of the priorities. In the literature, AHP has been widely used in solving many complicated decision-making problems [16,17,18].

In the AHP method, multiple pair-wise comparisons are based on a standardized comparison scale of nine levels (Table 1). The relevant index should be lower than 0.10 in order to accept the AHP results as consistent. If the final consistency ratio exceeds this value, the decision-maker should go back to redo the assessments and the comparison. Saaty [19] stated that in many practical cases, the pair-wise judgments of decision makers will contain some degree of uncertainty. It is usually the case that the AGHS equipment decision making team is certain about the rank order of the comparison elements but uncertain about the precise numerical values of the judgments. The traditional AHP method of overcoming this problem is to introduce a discrete linguistic set of comparison judgments. Instead of directly assigning numerical values to the comparison ratios, the AGHS equipment decision making team chooses an appropriate linguistic phrase that best corresponds to the comparison preferences.

3.2 The fuzzy FLP method

Bellman and Zadeh [20] proposed a fuzzy programming model for decision making in a fuzzy environment. Later on, their method was used by Zimmermann [21] to solve fuzzy linear programming (FLP) problems.

The analytical hierarchy process weighted fuzzy linear programming model (AHP-FLP) was employed in this research to solve AGHS equipment supplier selection problems of a practical appliance AGHS company based in Taiwan. This work attempts to address the shortfalls identified earlier based on a real-world application of the AHP-FLP method for AGHS equipment supplier selection problems.

4. The proposed model

The proposed model for the airport ground handling equipment supplier selection problem and the integer AHP-FLP approach consists of three basic stages: (1) identifying the criteria to be used in the model, (2) conducting AHP computations, (3) and making optimal choices using the AHP-FLP approach will help the AGHS company.

In the first phased of the proposed model, AGHS equipment supplier selection criteria that will be used for evaluation are determined and the decision hierarchy is formed. The AHP model is structured such that the objective is in the first level, the evaluation criteria are in the second level and alternatives for an AGHS equipment supplier are on the third level. In the last step of the first stage, the decision hierarchy is approved by the AGHS equipment supplier decision making team.

After the approval of the decision hierarchy, the criteria used in the AGHS equipment supplier selection are assigned weights using AHP in the second stage. In this phase, pair-wise comparison matrices are formed in order to determine the criteria's weights. The experts from the AGHS supplier selection team make individual evaluations using the scale provided in Table 1 to determine the values of the elements of the pair-wise comparison matrices.

In the second phased of the proposed model, the AHP method is used to calculate the weights of the criteria. Firstly, the weights of the criteria and the scores of the alternatives, which are called local priorities, are considered as decision elements in the second step of the decision process. The AGHS equipment supplier selection expert team is required to provide its preferences by pair-wise comparisons with respect to the weights and scores. The values of the weights v_i and scores r_{ij} are elicited from these comparisons and represented in a decision table. The third step of the AHP process aggregates all of the local priorities from the decision table by a weighted sum as shown below:

$$R_j = \sum_i v_i \times r_{ij}$$

The global priorities R_j thus obtained are finally used for ranking of the alternatives and selecting the best alternative.

The pair-wise comparison in the AHP process assumes that the AGHS equipment supplier selection expert team can compare any two elements E_i, E_j at the same level of the hierarchy and provide a numerical value a_{ij} for the ratio of their importance. If the element E_i is preferred to E_j, then $a_{ij} > 1$ .Correspondingly, the reciprocal property $a_{ij} = 1/a_{ij}$, j= 1, 2, 3, ...n and i = 1, 2, 3, ... n always holds. Each set of comparisons for a level with n elements requires $[n \times (n-1)]/2$ judgments. The second half of the comparison matrix is made up of the reciprocals of those judgments lying above the diagonals and it is usually omitted. Judgments are provided by means of a nine-point ratio scale that ranges from two factors being equally important to one of the factors being absolutely more important than the others.

After the expert team evaluates the AGHS equipment supplier selection criteria, local priorities for each element are calculated [3,22]. A local priority vector $w = (w_1, w_2, w_3, ... w_n)^T$ may be obtained from the comparison matrix by applying some prioritization techniques, such as the logarithmic least squares method or the eigenvalue method. The set of n relative priorities should be normalized to a sum of one:

$$\sum_{i=1}^{n} w_i = 1, \quad w_i > 1 \quad \text{and } i = 1, 2, 3, \ldots n$$

Thus, the number of independent local priorities is (n-1). When the AGHS equipment supplier selection expert team is perfectly consistent in its answers to pair-wise comparison questions then all elements a_{ij} have perfect values $a_{ij} = w_i / w_j$. In this AGHS equipment supplier selection case, $a_{ji} = a_{ik} a_{kj}$ for all i, j, k = 1, 2, 3, ...n.

In the second phased of the methodology, for AGHS equipment suppliers' selection problems, the collected data does not behave crisply and they are typically fuzzy in nature. In this section, the general fuzzy multi-objective model for AGHS equipment suppliers' selection is presented in the following manner [3,5,23]. The fuzzy multi-objective formulation for the AGHS equipment suppliers selection problems is solved the following way:

Find a vector X, $X = [x_1, x_2, x_3, \ldots x_n]$ that maximizes the supplier performance using objective function z_k with a number of m criteria:

$$\max \tilde{z}_k = \sum_{i=1}^{n} (c_{ki} \times x_i) \geq \sim z_k^0 \quad k=1,2,3, \ldots, n \tag{1}$$

and the following constraints:

$$\sum_{i=1}^{n} a_{ri} \times x_i \leq b_r \tag{2}$$

where c_{ki}, a_{ri} and b_r are crisp values.

In this model, the sign (~) indicates the fuzzy environment. The symbol ($\geq \sim$) denotes the fuzzified (mean is unclear or vague) version of $\geq$ and has the linguistic interpretation meaning "essentially greater than or equal to." z_k^0 is the aspiration level that the decision maker wants to reach.

Every objective function value, $\tilde{z}_k$, changes linearly from $z_k^{\min}$ to $z_k^{\max}$. So it may be considered as a fuzzy number with the linear membership function as shown in Figure 1.

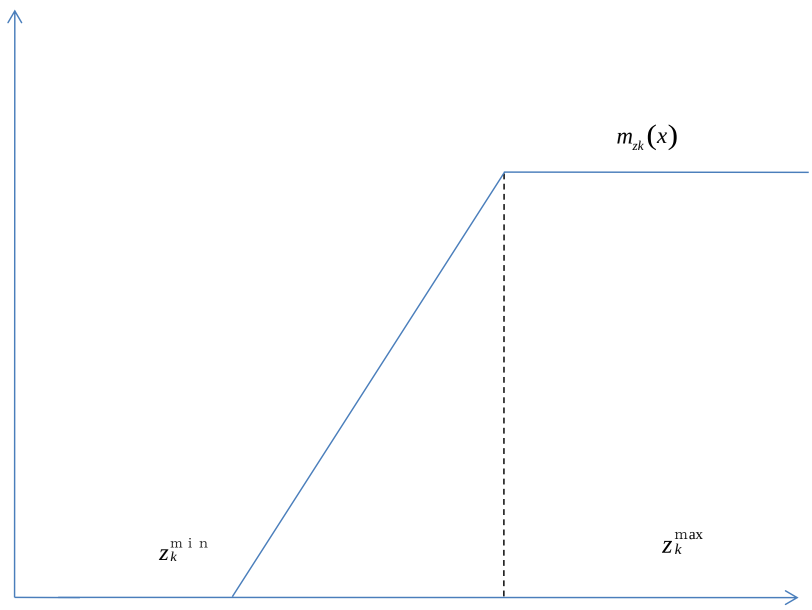

Fig. 1 Maximizing objective function as fuzzy number

z_k^{min} and z_k^{max} are obtained through solving the multi-objective problem as a single objective.

Based on the above-mentioned linear membership function, maximization goals ($\tilde{z}_k$) are given as follows:

$$\mu_{z1}(x)=\begin{cases} 1 & \text{for } z_k \geq z_k^{max} \\ \left(z_k^{max}-z_k(x)\right)/\left(z_k^{max}-z_k^{min}\right) & \text{for } z_k^{min} < z_k < z_k^{max} \\ 0 & \text{for } z_k \leq z_k^{min} \end{cases} \quad (3)$$

The model formulated in equations (1) and (2) can be solved using the weighted additive model which is widely used in vector-objective optimization problems; the basic concept is to use a single utility function to express the overall preference of the decision maker to draw out the relative importance of certain criteria [24]. In this approach, multiplying each membership function of fuzzy goals by its corresponding weights and then adding the results together obtains a linear weighted utility function (Zimmermann) [21].

$$\max \sum_{k=1}^{m}\left(w_k \times \lambda_k\right) \quad (4)$$

subject to:

$$\lambda_k \leq \mu_{z_k}(x) \tag{5}$$

$$\lambda_k \in [0,1] \text{ and } k = 1, 2, 3, \ldots n \tag{6}$$

$$\sum_{k=1}^{m} w_k = 1, w_k \geq 0 \tag{7}$$

$$x_i \geq 0, i = 1, 2, 3, \ldots m \tag{8}$$

where w_k and $\mu_{z_k}(x)$ represent the solution of the membership function, weighting coefficients that present the relative importance among the fuzzy goals and membership functions of the objective function.

In the third phased of the proposed model, the AHP-FLP approach will help an AGHS company makes optimal decisions and choices. Overall, the formulation of this proposed model can be expressed using the following steps:

Step 1: AGHS equipment supplier selection criteria are determined and the hierarchical structure of the best supplier selection is developed.

Step 2: The team of experts and authors conduct the weight calculation for each level in order to obtain the overall score for each AGHS equipment supplier with respect to all criteria and pair-wise comparisons of the main selection criteria.

Step 3: According to the identification of necessary criteria for airport ground handling equipment selection, the AGHS equipment supplier selection model is constructed.

Step 4: The lower bound ($z_k^{\min}$) and upper bound ($z_k^{\max}$) multi-objective AGHS equipment supplier selection problem is defined as a single objective linear programming model.

Step 5: $z_k^{\min}$ and $z_k^{\max}$ values are used to find the membership function for the

 doi:10.20944/preprints202012.0799.v1

criterion in equation (3).

Step 6: Based on the AHP weighted additive model, we formulate the equivalent crisp model of the fuzzy optimization problem according to equations (4)-(8).

Step 7: We find the optimal solution vector X, which is the efficient solution for the original AGHS equipment supplier selection problem.

Step 8: We compare the AHP and AHP-FLP results.

The general steps of an AHP weighted fuzzy linear programming approach [3] can be summarized as in the Figure 2.

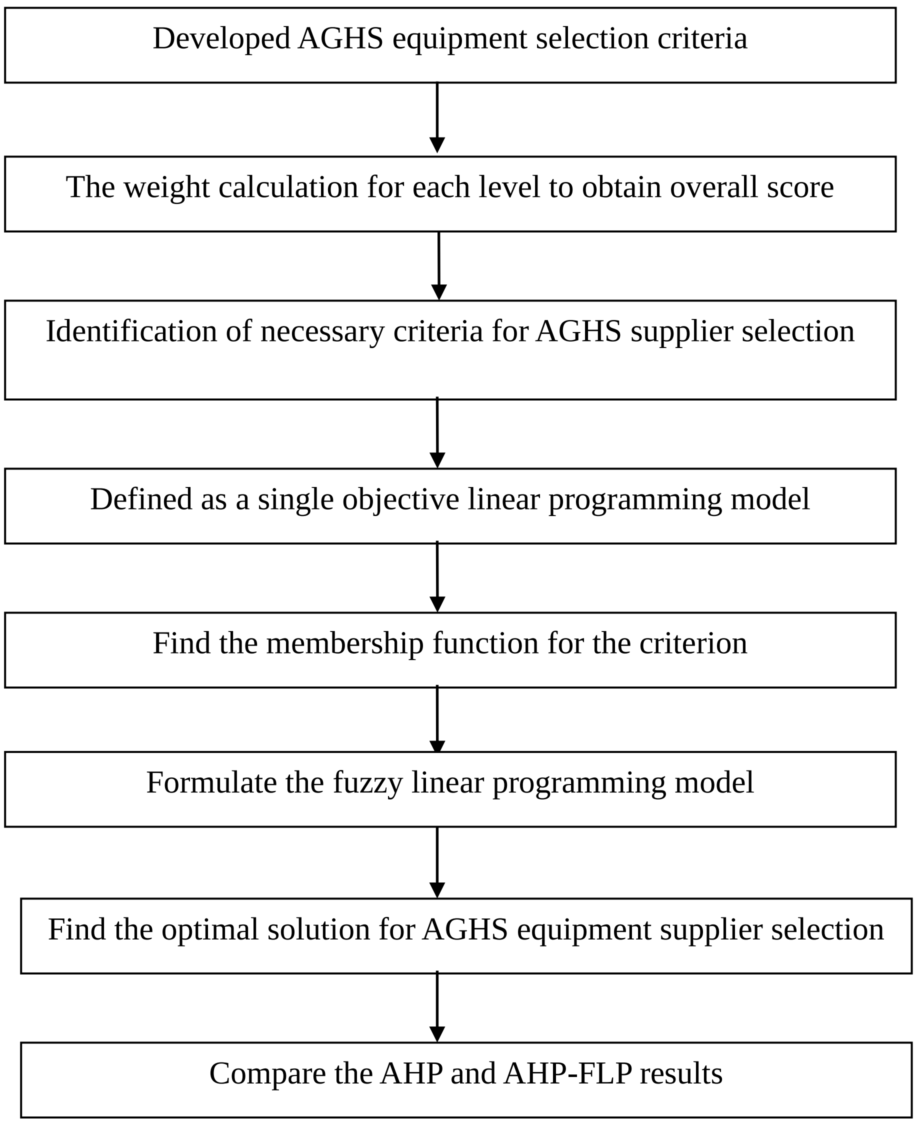

Figure 3 The steps of the proposed method

4.1 A Realistic Airport GHS Company Application of the Proposed Model

Taoyuan International Airport Services Co., Ltd (TIAS), a joint venture ground handling service company, is owned by China Airlines (49%), the Ministry of Transportation and Communications (45%), and the United Parcel Service (6%). TIAS offers a full range of handling services for all airlines and air cargo in Taoyuan Airport. TIAS is the first ground handler in Taiwan to acquire ISO 9001 accreditation, an internationally-recognized quality management systems used to maintain high quality service standards. TIAS, as a member of the International Air Transport Association Ground Handling Council (IGHC), keeps pace with international ground handling industry developments and is committed to providing better ground handling service. In 2018, TIAS had provided ground handling service to 81,789 flights, serviced over 27.2 million passengers, and handled over 1.82 million tons cargo volume. TIAS has powered ground handling equipment (vehicle quantity: 749) and non-powered ground handling equipment (vehicle quantity: 5,584).

The aim of our research was to evaluate the possible alternative airport ground handling equipment supplier selection problems and help decision makers in terms of AGHS company purchasing requirements. However, it is hard to select the most suitable supplier among the supplier alternatives having various characteristics.

For real-world application, an expert team was formed from two airport ground handling service department vice presidents and four senior technical supply and maintenance managers of the Taiwan AGHS company (e.g., TIAS) and from the authors to participate in this research. Thus, the criteria to be used in the model were determined by the expert team. Pair-wise comparison matrices were used to calculate criteria weights and these were also formed by the same expert team. The application that was performed is based on the aforementioned steps from the previous section and it is explained step-by-step together with the results.

4.2 Identification of Necessary Decision Criteria for Airport Ground Handling Equipment Selection

The decision criteria that should be considered in the selection of AGHS equipment suppliers were determined by the airport ground handling equipment supplier selection expert team. Past experience and the professional background of the expert team were used in the determination of the important criteria that should be used for airport ground handling equipment supplier selection. An explanation of the important criteria and their definitions are given in Table 1 [10, 13].

Table 1 AGHS equipment supplier decision criteria

Quality management	Quality assurance system (ISO/TS 16949/QS-9000/ISO 14001) policy and internal quality audits.
Production capacity and maintenance	Manufacturing capabilities include good use of statistical process control (SPC), lean manufacturing and a "kanban" system. Supplier innovation capabilities include hardware, software (CAD/CAE/CAM), knowledge, personnel and experience. The repair and maintenance service supports customer satisfaction.
Product warranty	Suppliers track warranties and have an evaluation process to determine what drives improvements in warranty costs and customer satisfaction
Provide technical transfer	The technological compatibility of the service, the material or the parts that are provided to the buying company is important.
Good cooperative relationship and reputation	A strong and successful buyer/supplier relationship requires mutual trust and understanding. The supplier has a good financial position in the industry
Reasonable parts price	The supplier provides reasonable parts prices.

Following the determination of the criteria, the AGHS equipment suppliers that were under development or in usage were investigated and an AGHS equipment supplier selection decision making team chose six important AGHS equipment suppliers criteria that are suitable for the AGHS company's needs. These are six criteria. They are: (SC1) quality management, (SC2) production capacity and maintenance, (SC3) product warranty, (SC4) providing technical transfer, (SC5) a good cooperative relationship and reputation, and (SC6) reasonable parts prices. These six important criteria were used in the evaluation and a decision hierarchy was established accordingly. The decision hierarchy, structured with the chosen AGHS equipment suppliers and their criteria is shown in Figure 3.

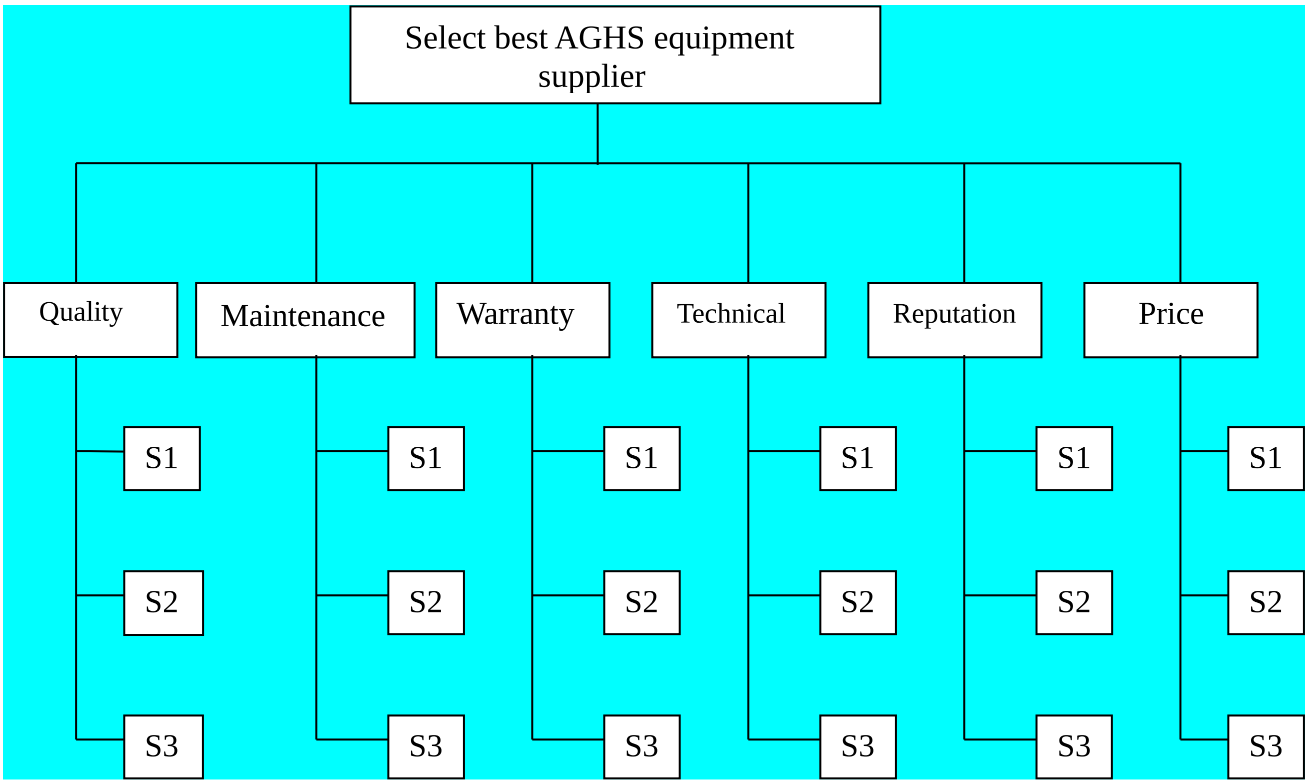

Fig. 3 Hierarchy of decision

4.3 Calculation of the Weights of the Criteria

After developing the decision hierarchy for this problem, the weights of the criteria that were going to be used in the evaluation procedures were computed using the AHP method. In this phase, the experts on the AGHS equipment selection team were given the duty of developing an individual pair-wise comparison matrix by using the scale provided in Table 2. Geometric means of these values are determined in order to obtain the pair-wise comparison matrix on which there is a consensus (Table 3). The outcomes obtained from the computations based on the pair-wise comparison matrix that is given in Table 4 are presented in Table 5.

Table 2 Criteria Matrix-original matrix

	Quality	Maintenance	Warranty	Technical	Reputation	Price
Quality	1	2	3	1/2	4	1/3
Maintenance	1/2	1	1/2	1/4	2	1/7
Warranty	1/3	2	1	1/3	2	1/6`
Technical	2	4	3	1	6	1/2
Reputation	1/4	1/2	1/2	1/6	1	1/9
Price	3	7	6	2	9	1

Table 3 the pair-wise comparison matrix criteria

Supplier Criteria	Weights(w)	λ_{max},C I,R I	C R
SC1 (Quality)	0.151	λ_{max} = 6.521	
SC2 (Maintenance)	0.062		
SC3 (Warranty)	0.079	CI = 0.104	0.084
SC4 (Technical)	0.241		
SC5 (Reputation)	0.039	RI = 1.24	
SC6 (Price)	0.428		

The SC1 (quality management), SC4 (product warranty) and SC6 (providing technical transfer) were determined to be the three most major criteria in the AGHS equipment selection process by AHP. A consistency ratio of the pair-wise comparison

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matrix is computed to be 0.084 < 0.1. Therefore, the weights were shown to be consistent and they were used in the following selection procedures.

4.3.1 Constructing a Linear Programming Model for Application

The hierarchical structure of the supplier selection process was identified based on the evaluations of our responding AGHS equipment supplier selection team. The overall score for each supplier with respect to all of the six criteria and pair-wise comparisons of the main selection criteria were obtained. Table 5 presents the local weights of each equipment supplier with respect to the main supplier selection criteria.

Table 4 Criteria matrix –adjusted matrix

	Quality	Maintence	Warranty	Technical	Reputation	Price	weights (row verage)
Quality	0.141	0.121	0.214	0.120	0.167	0.148	0.152
Maintence	0.071	0.061	0.036	0.060	0.083	0.063	0.062
Warranty	0.047	0.121	0.071	0.060	0.083	0.074	0.079
Technical	0.282	0.242	0.214	0.240	0.250	0.222	0.241
Reputation	0.035	0.030	0.036	0.040	0.042	0.049	0.039
Price	0.424	0.424	0.429	0.480	0.375	0.444	0.428

Table 5 Pair-wise comparison of suppliers with respect to each evaluation criteria

DMU	Supplier1	Supplier2	Supplier3	AHP Weights
Quality				
Supplier1	1	3	5	0.633
Supplier2	1/3	1	3	0.260
Supplier3	1/5	1/3	1	0.106
Consistency ratio				0.033
Maintenance				
Supplier1	1	1/3	1/9	0.077
Supplier2	3	1	1/3	0.231
Supplier3	1/9	3	1	0.692
Consistency ratio				0.000
Warranty				
Supplier1	1	1/5	1/9	0.064
Supplier2	5	1	1/3	0.267
Supplier3	9	3	1	0.669

Consistency ratio				0.025
Technical				
Supplier1	1	1/9	1/7	0.057
Supplier2	9	1	3	0.649
Supplier3	7	1/3	1	0.295
Consistency ratio				0.070
Reputation				
Supplier1	1	1/5	1/4	0.096
Supplier2	5	1	3	0.619
Supplier3	4	1/3	1	0.284
Consistency ratio				0.0923
Price				
Supplier1	1	3	5	0.633
Supplier2	1/3	1	3	0.260
Supplier3	1/5	1/3	1	0.106
Consistency ratio				0.0419

Table 6 Overall score calculation

	Quality	Maintenance	Warranty	Technical	Reputation	Price	Score
Supplier A1	0.096	+ 0.005	+0.005	+0.014	+0.004	+0.271	= 0.395*
Supplier A2	0.039	+ 0.014	+ 0.021	+0.156	+0.024	+0.111	= 0.365
Supplier A3	0.016	+ 0.043	+ 0.053	+0.071	+0.011	+0.045	= 0.239
Rrow average	0.151**	0.062	0.079	0.241	0.039	0.428	

Notes: 1. 0.395* = 0.633×0.151=0.096+0.077×0.062=0.005+0.064×0.079=0.005+0.057×0.241=0.014+0.096×0.039=0.004+0.633×0.428=0.271.
2. 0.151**= 0.096+0.039+0.016.

Table 7 Input data for Airport GHS equipment supplier selection

	Quality	Maintenance	Warranty	Technical	Reputation	Price
Supplier 1 (x_1)	0.096	0.005	0.005	0.014	0.004	0.271
Supplier 2 (x_2)	0.039	0.014	0.021	0.156	0.024	0.111
Supplier 3 (x_3)	0.016	0.043	0.053	0.071	0.011	0.045
Row Averages	0.151	0.062	0.079	0.241	0.039	0.428

To illustrate the use of the linear programming model in AGHS equipment supplier selection, a detailed method can be seen in [3]. Then, the linear membership

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function is used for fuzzifying (maen is unclear or vague) the objective functions and the constraint for the above-mentioned problem. The dataset for the values of the lower ($z_k^{\min}$) and upper ($z_k^{\max}$) bounds of the objective functions are provided in Table 8.

Table 8 Dataset for the membership functions

	$z_k^{\min}(\mu=0)$	$z_k^{\max}(\mu=1)$
z_1 – Quality	0.016	0.096
z_2 – Maintenance	0.005	0.043
z_3 – Warranty	0.005	0.053
z_4 – Technical	0.014	0.156
z_5 – Reputation	0.004	0.024
z_6 – Price	0.045	0.271

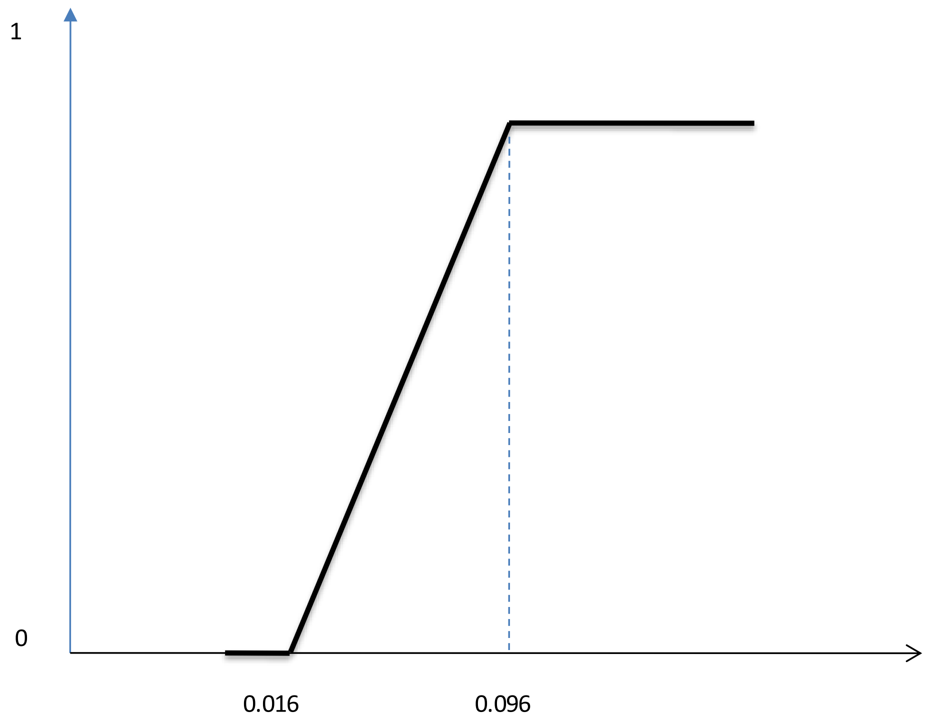

Figure 4 Membership function of Quality

4.3.2 Finding the Fuzzy Multi-Objective Model

In this stage, the membership functions for six objective functions and the constraint were provided so as to maximize the performance of the suppliers related to each main AGHS equipment supplier's selection criterion. To exemplify this, we take the quality criteria to show the membership function of Z_1.

The membership function of z_1 (quality), which is shown in Figure 4, is computed according to the equation (3):

$$\mu_{z1}(x)=\begin{cases} 1 & \text{for } z_1 \geq 0.096 \\ (0.096 - z_1(x))/(0.096 - 0.016) & \text{for } 0.016 < z_1(x) < 0.096 \\ 0 & \text{for } z_1 \leq 0.016 \end{cases} \quad (9)$$

The fuzzy linear model formulation of the application is shown below.

Find a vector X, X =[x_1, x_2, x_3] to satisfy:

$$\max\ \tilde{z}_1 = 0.096\,x_1 + 0.039\,x_2 + 0.016\,x_3 \gtrsim z_1^0$$

$$\max\ \tilde{z}_2 = 0.005\,x_1 + 0.014\,x_2 + 0.043\,x_3 \gtrsim z_2^0$$

$$\max\ \tilde{z}_3 = 0.005\,x_1 + 0.021\,x_2 + 0.053\,x_3 \gtrsim z_3^0$$

$$\max\ \tilde{z}_4 = 0.014\,x_1 + 0.156\,x_2 + 0.071\,x_3 \gtrsim z_4^0$$

$$\max\ \tilde{z}_5 = 0.004\,x_1 + 0.024\,x_2 + 0.011\,x_3 \gtrsim z_5^0$$

$$\max\ \tilde{z}_6 = 0.271\,x_1 + 0.111\,x_2 + 0.045\,x_3 \gtrsim z_6^0$$

subject to :

$$x_1 + x_2 + x_3 = 1$$

$$x_i \geq 0,\ i = 1, 2, 3.$$

4.3.3. Developing the AHP-FLP Model

In this case, the weights (w_k) related to the *k*th objective are taken from pair-wise comparisons of the main AGHS equipment supplier's selection criteria using the AHP provided in Table 7, as "row averages." It can be seen from Table 5, Table 6 and Table 7, that the total weights are equal to one (the detailed method can be seen in [10]).

Based on the AHP weighted additive model and equations (4)-(8), the crisp single objective programming model, which is equivalent to the above-mentioned fuzzy linear model can be written as follows:

$$\text{Max } 0.151\,\lambda_1 + 0.062\,\lambda_2 + 0.079\,\lambda_3 + 0.241\,\lambda_4 + 0.039\,\lambda_5 + 0.428\,\lambda_6$$

subject to:

$$\lambda_1 \le \frac{0.096-(0.096x1+0.039x2+0.016x3)}{0.096-0.016}$$

$$\lambda_2 \le \frac{0.043-(0.005x1+0.014x2+0.043x3)}{0.043-0.005}$$

$$\lambda_3 \le \frac{0.053-(0.005x1+0.021x2+0.053x3)}{0.053-0.005}$$

$$\lambda_4 \le \frac{0.1564-(0.014x1+0.156x2+0.071x3)}{0.156-0.014}$$

$$\lambda_5 \le \frac{0.024-(0.004x1+0.024x2+0.011x3)}{0.024-0.004}$$

$$\lambda_6 \le \frac{0.271-(0.271x1+0.111x2+0.045x3)}{0.271-0.045}$$

$$\lambda_i \ge 0, \lambda_i \le 1, \quad i = 1, 2, 3, 4, 5, 6.$$

4.3.4 Solving AHP-FLP Model

The linear programming software Lingo is used to solve this problem, and the optimal solution is obtained as follows:

$x_1 = 0$, $x_2 = 0$, $x_3 = 1$, suggesting that AGHS equipment supplier A3 is the best choice according to the decision maker's preferences.

Objective (Z_k) and membership ($\mu_{zk}(x)$ or λ_k) function values are obtained as follows:

$z_1 = 0.016$, $z_2 = 0.043$, $z_3 = 0.053$, $z_4 = 0.071$, $z_5 = 0{,}011$, $z_6 = 0.045$

$\mu_{z1}(x) = \lambda_1 = 0$, $\mu_{z2}(x) = \lambda_2 = 1$, $\mu_{z3}(x) = \lambda_3 = 1$, $\mu_{z4}(x) = \lambda_4 = 0.401$,

$\mu_{z5}(x) = \lambda_5 = 0.350$, $\mu_{z6}(x) = \lambda_6 = 0$.

The membership functions values show that the achievement levels of Z_3, the product warranty , Z_4, providing technical transfer, and Z_6, reasonable parts prices, are greater than Z_1, the quality management , Z_2, production capacity and maintenance and Z_5, good cooperative relationship and reputation. In other words, the achievement level of the objective functions corresponds to the priority of the supplier selection criteria (based on the decision maker's preferences), indicating that AGHS equipment supplier A3 is the optimum AGHS equipment supplier.

4.3.5 Comparing the AHP and AHP-FLP Model Results

Table 10 shows the overall scores of the each supplier using the AHP and AHP-FLP model. As noted earlier, AGHS equipment supplier A1 was identified as the best supplier using the crisp AHP approach under no restrictions. When the AHP-FLP model that is subject to constraints was employed, AGHS equipment supplier A3 was identified as the most suitable supplier. The finding that AGHS equipment supplier A3 was identified as the most appropriate supplier under the AHP-FLP model also tends to confirm the views of the AGHS equipment selection team, supporting our argument that the AHP-FLP approach is somewhat superior to the AHP approach.

Table 10 Comparing the AHP and AHP-FLP model results

	AHP	AHP-FLP
AGHS equipment supplier A1	0.385*	0.000
AGHS equipment supplier A2	0.370	0.000
AGHS equipment supplier A3	0.097	1.000

Note: 0.385*=0.574×0.151+0.077×0.062+0.064×0.079+0.057×0.241+0.096×0.039+0.633×0.428

5. Conclusion and Implications

5.1 Conclusion

Airport ground handling equipment supplier selection is an important issue and affects an AGHS company in its daily duties and work safety. Our research presenting an comparing AHP and AHP-FLP model to evaluate AGHS equipment suppliers used triangular fuzzy numbers to express linguistic values that consider the subjective judgments of evaluators and then adopts the AHP-FLP model to synthesize the group decision. Thus, we demonstrate a real example for an AGHS company case in Taiwan.

This paper concludes that the AHP-FLP model outperforms the AHP method for AGHS equipment supplier selection with respect to restricted supplier selection criteria. Of the six AGHS equipment suppliers in this AGHS company case, AGHS equipment supplier A1 was identified as the best supplier with the use of the AHP model under no restrictions. After using AHP-FLP model is contradicts the finding that AGHS equipment supplier A3 was selected as the best supplier by the AHP-FLP model. In this case, this model can effectively handle the vagueness and imprecision of input data and the varying importance of criteria in the AGHS equipment supplier selection problem. The findings of this study suggest that the weights of AGHS supplier selection criteria calculated by the AHP-FLP model are in line with the real AGHS equipment supplier selection decisions of AGHS purchasing managers.

5.2 Management Implications

This model compares the AHP and AHP-FLP methods for use in AGHS equipment suppliers' selection problems. The integrated model can help the DM to find out the appropriate ordering from each AGHS equipment supplier, and it allows AGHS company purchasing managers easily to select the optimal equipment supplier for quality management, production capacity and maintenance, product warranty, providing technical transferring, a good cooperative relationship and reputation, and reasonable parts prices. It can also be used with little modifications in other decision making problems for an AGHS company in different countries or others airport industries.

5.3. Future Directions

One possible limitation of the model concerns the multi-attribute weighting method. Weights determined by the AHP method are considered to be complete subjective weights. The data envelopment analysis (DEA) method is partially based on strict optimization by linear programming, and it can be considered as objective. Some studies (e.g., Ramanathan, 2006) [14] showed that weights could be determined by the DEA method. Weights that combined objectivity with subjectivity might be much better the ones only with subjectivity. This is a direction for future research.

Author Contributions: Conceptualization, T.Y.J.; formal analysis, T.C.S and T.Y.J; writing—original draft preparation, T.Y.J and T.C.S; writing—review and editing, T.C.S and T.Y.J.; planning all works in the study and supervision, L.H.S.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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doi:10.20944/preprints202012.0799.v1