

Multi-Criteria Decision-Making Techniques for Solving the Airport Ground Handling Service Equipment Vendor Selection Problem

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Abstract

The airport ground handling service (AGHS) equipment vendor selection (AGHSEVS) problem is critical for ramp work safety management, because AGHS equipment malfunctions affect airport ramp work safety. Appropriate vendor selection can prevent aircraft damage and delays in airlines schedules, and ensure reliable and high-quality ground handling service. The AGHSEVS problem is a time-consuming and complex process that requires professional knowledge and experience to make judgments. Specifically, AGHSEVS is a multi-criteria decision-making (MCDM) problem. Previous research has seldom integrated MCDM methods with linear and goal programming to solve the AGHSEVS problem. The objective of this study was to develop a new system evaluation model for AGHSEVS by considering both qualitative and quantitative methods. We test the proposed approach on an AGHS company in Taiwan.

Key words: equipment vendor selection; fuzzy TOPSIS; fuzzy weighted average left and right score; multi-choice goal programming; multi-aspiration goal programming

1. Introduction

A crucial task of airport ground handling service (AGHS) companies is to conduct diverse ground handling service processes on airport ramps. Two major types of ground handling service procedures are generally distinguished: terminal operations and ramp operations. In this paper, we focus on ramp operations because they require complex tasks and a diversity of AGHS equipment. As a service of AGHS companies, ramp handling (i.e., ground handling service) includes the loading and unloading of airplanes and the transport of passengers, crew, baggage, freight and mail between airplanes and terminal buildings. In general, this can be classified as an AGHS logistics service. This service is typically provided by a third party ground handler (i.e., an AGHS company), the airline itself, or by the ramp handling business unit of an airport [1, 2]. From the above description we can know the AGHS company main job is working on the ramp handling safely. However, select the most suitable equipment is difficult, because characteristics vary. This makes the job of ground handlers for AGHS companies more difficult, because equipment malfunctions can affect work safety on the airport ramps. Effective AGHS has benefits such as preventing aircraft damage (collisions with ground handling equipment) and delays, reducing the turnaround time of ground services and ground handling costs, and ensuring high handling reliability [37]. To avoid the aforementioned problem, AGHS companies rely on high-tech equipment to solve AGHS equipment vendor selection (AGHSEVS) problems. Most AGHS companies are concerned with equipment performance and quality. Numerous AGHS equipment is available. We therefore complied a list of generally required AGHS equipment, including aircraft towing trucks, main deck loaders, container pellet loaders, conveyor belt loaders, passenger step vehicles, ground power units, air starter units, catering trucks, and cargo towing tractors. Aircraft towing trucks are vital pieces of equipment. There are several types

of aircraft towing trucks designed to push and tow aircraft. Aircraft towing trucks can tow aircraft weighting up to 100 metric tons [3]. Acquisition of an aircraft towing truck that satisfies operational performance, equipment quality, and ease of usage requirements is crucial to improving the operational safety of an AGHS company [4]. Hence, formulating a purchasing list of required AGHS equipment is regarded as both a decision-making problem and a reflection of company preference. AGHSEVS is a strategic problem that has a substantial effect on the safety of ramps work. Addressing AGHSEVS problems is a time-consuming and complex process that requires professional knowledge and experience for making judgments [10]. Thus, selecting an optimal equipment vendor is a multi-criteria decision making (MCDM) problem. The AGHSEVS process may be particularly complicated for AGHS company managers. Before an AGHS company purchases new equipment (such as a vehicle), it should analyze its finances and options, because budget constraints can limit the types of equipment that can be purchased. Most AGHS companies rank safety high among their purchasing considerations when buying new equipment. Other important attributes include fuel economy, comfort, convenience features, insurance information, technical specifications, warranties, and resale value [6]. As the AGHS market becomes increasingly competitive, continual changes within AGHS companies demand that leading manufactures provide them with new and technologically superior equipment. Thus, an analytic decision-making method for selecting optimal AGHS equipment is useful to both the AGHS company and the equipment manufacturer. An analytic method not only reduces the buyer's burden but also may increase equipment sales. Additionally, it plays a strategic role by improving customer services within the competitive AGHS market environment. Although AGHSEVS is a crucial aspect of ramp operations, research on this subject is limited. A study by Bard

and Sousk (1990) suggested the use of the analytic hierarchy process (AHP) to select the next generation of rough terrain cargo handlers for the U.S. Army [4]. Most relevant studies have employed MCDM methods to make equipment choices. Shang and Sueyoshi (1995) developed a decision support framework with three modules (AHP, simulation and accounting procedures) to assist managers in selecting the most appropriate flexible manufacturing system designs [7]. Lin and Yang (1996) recommended establishing a knowledge-based (i.e., expert system) model using the AHP for the selection of optimal machinery [8]. Chan et al., (2001) suggested an expert consultant system for the selection of material-handling equipment suitable for the movement and storage of materials in a manufacturing system [9]. Certain studies have proven particularly valuable for evaluating equipment, such as [10] who proposed a systematic evaluation model using AHP and fuzzy technique for order preference by similarity to ideal solution (TOPSIS) methods to help agents in defense industries select optimal weapons equipment among a set of available alternatives in a fuzzy environment. They utilized a MCDM method to determine the weight of evaluation criteria, and adopted a fuzzy TOPSIS method to obtain the performance ratings of feasible alternatives in linguistic values, parameterized using triangular fuzzy numbers. However, the fuzzy AHP process is impractical in some cases. Because of the numerous potential available choices and criteria [11, 12], a fuzzy AHP decision approach may produce fatigue among DMs caused by repetitive measurements. Therefore, to avoid an unreasonably large number of pairwise comparisons, the fuzzy TOPSIS method is suitable for achieving an optimal ranking result. The aforementioned research offers a starting point. Regarding evaluation and selection problems, a decision-making model is required to select an optimal solution from the proposed alternatives [43]. However, previous research has rarely integrated

the MCDM method with linear programming (LP) and goal programming (GP) approaches to solve the AGHSEVS problem. In reality, conflicting resources and incomplete information cause substantial difficulty for DMs in constructing a reliable mathematical model to illustrate their preferences [44]. To overcome this problem, numerous approaches have been developed and numerous methodologies have been applied. Generally, GP entails applying the logic of optimization in mathematical programming to satisfy several goals of the DMs [45]. For verifying an LP model, we employed multi-choice goal programming (MCGP) and multi-aspiration goal programming (MAGP) to perform comparative analyses.

The objective of this study was to help AGHS company managers adopt simple, systematic methods for obtaining high-quality equipment vendors. Additionally, we attempted to avoid the inherent drawbacks of using group decision-making systems to solve the AGHSEVS problem. We therefore incorporated experimental methods (AHP, fuzzy TOPSIS, LP, and GP) for facilitating AGHSEVS to provide a reliable framework as a valuable reference for equipment buyers and suppliers.

The remainder of this paper is structured as follows: section 2 briefly describes our proposed method, section 3 proposes and describes in detail a model for the AGHSEVS, and section 4 presents a conclusion wherein management implications are discussed.

2. Methods

In this study, we employed three MCDM methods, namely the AHP method, the fuzzy TOPSIS method, and the fuzzy weighted average (FWA) left and right score, and LP and GP methods, namely MAGP and MCGP, to solve the AGHSEVS problem.

2.1 AHP Method

The AHP is a decision-support procedure developed by Saaty [46] for addressing

complex, unstructured, multi-criteria decisions. The AHP is based on three factors: the structure of the model, the comparative evaluation of alternatives, and the criteria and synthesis of priorities. In the literature, the AHP has been widely used to solve numerous complicated decision-making problems [10, 16, 26]. In step 1, a complex decision problem is structured as a hierarchy. The AHP initially deconstructs complex MCDM problems into a hierarchy of interrelated decision elements. Objectives, criteria, and alternatives are arranged in a hierarchical structure similar to a family tree. In Step 2, alternatives and criteria are compared. Once the problem has been deconstructed and a hierarchy has been formulated, a prioritization procedure for determining the relative importance of criteria within each level begins. A pair-wise judgment starts at the second level and ends at the lowest level of alternatives. At each level, criteria are compared pair-wise according to their levels of influence and on the basis of the specified criteria in higher levels [35].

In the AHP, multiple pair-wise comparisons are based on a standardized comparison scale of nine levels (Table 1).

Please insert Table 1 here

In Step 3, $C = \{ C_j \mid j = 1, 2 \dots n \}$ represents the set of criteria. The result of the pair-wise comparison of n criteria can be summarized in an $(n \times n)$ evaluation matrix D in which every element d_{ij} ($i, j = 1, 2, \dots, n$) is the quotient of weights of the criteria, as in Eq.1.

$$D = \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ d & d_{n2} & \dots & d_{nn} \end{bmatrix}, d_{ii}=1, d_{ji}=1/d_{ij}, d_{ij} \neq 0 \quad (1)$$

In Step 4, a mathematical process is used to normalize and calculate the relative weights for each matrix. Relative weights are determined by the eigenvector (w)

corresponding to the largest eigenvalue (λ_{\max}):

$$D_W = \lambda_{\max} W \quad (2)$$

If the pair-wise comparisons are completely consistent, the matrix D has rank 1, and $\lambda_{\max} = n$. Under this condition, weights can be obtained by normalizing any of the rows or columns of D [5, 10]. In Step 5, the quality of the output of the AHP becomes strictly related to the consistency of the relation between the entries of D ; that is, $d_{ij} \times d_{jk} = d_{ik}$. The consistency index (CI) is

$$CI = \frac{(\lambda_{\max} - n)}{(n - 1)} \quad (3)$$

Step 6, entails delineating the final consistency ratio (CR), which indicates whether the evaluations are sufficiently consistent. The final CR is calculated as the ratio of CI and the random index (RI), as indicated in the following.

$$CR = CI/RI \quad (4)$$

RI should be lower than 0.10 to accept the AHP results as consistent. If the final CR exceeds this value, the DM should return to Steps 2 and 3 and perform the assessments and comparison again. The consistency measurement can be used to evaluate the consistency of the overall hierarchy [10, 17, 18].

2.2 TOPSIS Method

TOPSIS was proposed by Hwang and Yoon [19]. The ideal solution, also termed the positive ideal solution, is a solution that maximizes beneficial criteria and attributes and minimizes cost criteria and attributes, whereas the negative ideal solution, also termed the anti-ideal solution, maximizes the cost criteria and attributes, and minimizes the benefit criteria and attributes. According to this technique, the optimal choice is the one that is nearest to the ideal solution and farthest from the negative ideal solution. That is, the positive ideal solution is composed entirely of

optimal values attainable from the criteria, whereas the negative ideal solution consists entirely of the worst values attainable from the criteria [20]. Numerous studies have employed TOPSIS to solve MCDM problems [21, 23, 24].

2.3 Fuzzy TOPSIS Method

With the traditional formulation of TOPSIS, personal judgments are represented by crisp values. However, in many practical cases, human preferences are uncertain and DMs might be reluctant or unable to assign crisp values to the judgments [10, 26]. The use of fuzzy set theory Zadeh (1965) enables DMs to incorporate unquantifiable information, incomplete information, and non-obtainable information into a decision model [33,6,10]. The fuzzy TOPSIS method can address ambiguities, uncertainties and vagueness in decision-making, which otherwise would be handled using crisp values. In its feasible applications, the triangular form of the membership function is frequently used to represent fuzzy numbers [10, 28, 29, 30, 31]. In the following subsection, the basic definitions and notation of fuzzy sets are provided and are used hereafter unless otherwise stated [32].

2.4 FWA Left and Right Scores

In this study, the FWA left and right scores were utilized to select optimal AGHS equipment [39]. The FWA algorithm based on left and right scores is provided as follows:

Step 1: Set the linguistic variables for the importance of criteria and rating of alternatives, represented by fuzzy numbers.

Step 2: Evaluate the importance of criteria on the basis of the linguistic variables provided in Step 1.

Step 3: Let the fuzzy numbers $A = (a_1, b_1, c_1)$, $B = (a_2, b_2, c_2)$ and $C = (a_3, b_3, c_3)$. Aggregate the fuzzy numbers as follows:

$$AFN = \left(\frac{(a_1 + b_1 + c_1)}{3}, \frac{(a_2 + b_2 + c_2)}{3}, \frac{(a_3 + b_3 + c_3)}{3} \right).$$

Step 4: Normalize the fuzzy decision matrix to determine cost and benefit criteria:

$$\left(\tilde{y}_{ij} \right)_N = \left(\left(a_{ij} \right)_N, \left(b_{ij} \right)_N, \left(c_{ij} \right)_N \right)$$

$$= \left[\frac{a_{ij} - a_j^{\text{Min}}}{\Delta_{\text{Min}}^{\text{Max}}}, \frac{b_{ij} - a_j^{\text{Min}}}{\Delta_{\text{Min}}^{\text{Max}}}, \frac{c_{ij} - a_j^{\text{Min}}}{\Delta_{\text{Min}}^{\text{Max}}} \right], j = 1, \dots, n; j \in \Omega_b$$

$$\left(\tilde{y}_{ij} \right)_N = \left(\left(a_{ij} \right)_N, \left(b_{ij} \right)_N, \left(c_{ij} \right)_N \right)$$

$$= \left[\frac{a_{ij} - a_j^{\text{Max}}}{\Delta_{\text{Max}}^{\text{Min}}}, \frac{b_{ij} - a_j^{\text{Max}}}{\Delta_{\text{Max}}^{\text{Min}}}, \frac{c_{ij} - a_j^{\text{Max}}}{\Delta_{\text{Max}}^{\text{Min}}} \right], j = 1, \dots, n; j \in \Omega_c$$

where

$$\left(a_{ij}, b_{ij}, c_{ij} \right)_N = \text{normalized fuzzy number} \square$$

$$c_j^{\text{Max}} = \text{Max } c_{ij}, \quad c_j^{\text{Min}} = \text{Min } a_{ij}, j = 1, \dots, n$$

$$\Delta_{\text{Min}}^{\text{Max}} = c_{\text{Min}}^{\text{Max}} - a_j^{\text{Min}}, \quad \Delta_{\text{Max}}^{\text{Min}} = c_j^{\text{Min}} - a_j^{\text{Max}}$$

Ω_b = set of benefit criteria

Ω_c = set of cost criteria

Step 5: Calculate the left (L_s)_{ij} and right scores (R_s)_{ij} by using the following formulas:

$$(L_s)_{ij} = \frac{\left(b_{ij} \right)_N}{1 + \left(b_{ij} \right)_N - \left(a_{ij} \right)_N} \quad \text{and} \quad (R_s)_{ij} = \frac{\left(c_{ij} \right)_N}{1 + \left(c_{ij} \right)_N - \left(b_{ij} \right)_N}$$

Step 6: Evaluate the alternatives with respect to the criteria on the basis of the linguistic variables provided in Step 1.

Step 7: Determine the average fuzzy Number, normalized fuzzy weights and left and right scores of alternatives with respect to the criteria by repeating Steps 3, 4 and 5.

Step 8: Calculate the value of the FWA by integrating the left and right scores for criteria and alternatives simultaneously:

$$\text{FWA, } \theta_i = \frac{w_1 r_{i1} + w_2 r_{i2} + \dots + w_m r_{im}}{w_1 + w_2 + \dots + w_m} = \frac{\sum_{j=1}^m (w_j \times r_{ij})}{\sum_{j=1}^m w_j}$$

where

w_j = left and right scores of criteria

r_{ij} = left and right scores of alternatives.

Step 9: Calculate the average of FWA value $(\theta_i)_{\text{Average}}$, for each alternative using: \square

$$\square \square \square \quad (\theta_i)_{\text{Average}} = \frac{(\theta_i)^U + (\theta_i)^L}{2}, \quad j = 1, \dots, n,$$

where

$(\theta_i)^U$ = the upper interval for each alternative

$(\theta_i)^L$ = the lower interval for each alternative.

Step 10: Rank the alternatives according to the average values in descending order to obtain the final results.

3. Three Models of AGHSEVS

3.1 LP Model for AGHSEVS

In current complex organizations, DMs do not attempt to maximize a well-defined utility function. Conflicts of interest and the incompleteness of available information make it nearly impossible to construct a reliable mathematical representation of DM preferences. Utilizing these deviational variables, we adopted the LP model proposed by Guneri et al. [41].

The objective function and constraints of the LP approach for AGHSEVS are as follows:

3.1.2 Nomenclature

CC_i closeness coefficients of i th vendor

X_i order quantity for i th vendor

D	total demand (30 units in the model)
q_i	defect quality rate of i th vendor
Q	company's maximum acceptable defect quality rate (0.04 in the model)
P_i	unit price of i th vendor
P	company's maximum acceptable unit price with respect to the allocated budget for purchasing the order (9.2 million US dollar in the model)
C_i	capacity of i th vendor

$$\text{Max (TVP)} = \sum_{i=1}^n CC_i X_i \quad (\text{objective function}) \quad (5)$$

Subject to

$$\sum_{i=1}^n X_i = D \quad (\text{demand constraint}) \quad (6)$$

$$\sum_{i=1}^n X_i p_i \leq PD \quad (\text{purchase cost budgeting constraint}) \quad (7)$$

$$\sum_{i=1}^n X_i q_i \leq QD \quad (\text{AGHS equipment quality constraint}) \quad (8)$$

$$X_i \leq C_i \quad (\text{vendor capacity constraint}) \quad (9)$$

$$X_i \leq 0, \quad i = 1, 2, \dots, n \quad (\text{non-negativity constraint}) \quad (10)$$

Eq. (5) is the objective function of total value purchasing (TVP), Eq. (6) represents the demand constraint of the AGHS company, Eq. (7) represents the budgeting constraint of the AGHS company, Eq. (8) represents the equipment quality constraint of each vendor, Eq.(9) represents the capacity constraint of each vendor, and Eq. (10) represents the non-negativity constraint which prohibits negative orders.

3.2 MCGP Model for AGHSEVS

GP, proposed by Charnes, Cooper, and Ferguson (1955) [47], is the most widely used approach in MCDM [45]. It is designed to address problems involving multiple conflicting objectives [43]. The MCGP approach includes many modified GP methods

conceived by previous scholars. To improve the utility of the GP techniques, Chang (2008) developed a multi-choice aspiration level (MCAL) model for solving multi-objectives decision-making (MODM) problems [48]. Chang's proposed approach differs considerably from fuzzy GP, because his model incorporates membership functions for addressing MODM problems with imprecise goal aspiration levels. This decision-making method can be used to set various aspiration levels, and can sort solution strategies (e.g., the higher the aspiration level achieved, the more favorable the outcome). The MCAL model can be employed to determine the most suitable resources for achieving higher aspiration levels at the initial stage of the resolution process. A typical MCGP problem is described as follows.

In real decision-making problems, goals are often interrelated. This problem is addressed in the following MCGP equations:

$$\text{Minimize} \quad \sum_{i=1}^n [(d_i^+ + d_i^-) + (e_i^+ + e_i^-)] \quad (11)$$

Subject to

$$f_i(X)b_i - d_i^+ + d_i^- = b_i y_i \quad i = 1, 2, \dots, n, \quad (12)$$

$$y_i - e_i^+ + e_i^- = g_{i,\min} \quad i = 1, 2, \dots, n, \quad (13)$$

$$g_{i,\min} \leq y_i \leq g_{i,\max} \quad i = 1, 2, \dots, n, \quad (14)$$

$$d_i^+, d_i^-, e_i^+, e_i^- \geq 0, \quad i = 1, 2, \dots, n. \quad (15)$$

As illustrated in Eqs. (12), (13), and (14), there are no selection restrictions for a single goal, but some dependent relationships exist among the goals. For instance, we can add the auxiliary constraint $b_i \leq b_{i+1} + b_{i+2}$ to the MCGP model, where b_i , b_{i+1} and b_{i+2} are binary variables. Consequently, b_{i+1} or b_{i+2} must equal 1 if $b_i = 1$. This means that if goal 1 has been achieved, then either goal 2 or goal 3 has correspondingly been achieved.

3.3 MAGP Model for AGHSEVS

Hosseini and Attarpour (2012) integrated MAGP and MCGP to solve multi-aspiration problems [38]. For comparison with the MCGP model, we adopted an MAGP model for AGHSEVS. In this section, an AGHS company's usage of MAGP is introduced. Aircraft towing truck vendor are classifies into five types ($X_1 \dots X_5$) in five manufacture areas (i.e., X_1 : Hong Kong, X_2 : Japan, X_3 : United States, X_4 : France and X_5 : Germany), which serve as manufacturer market segments in this real case. The AGHS company managers seek to achieve four predetermined goals. These goals are Goal 1 (g_1) the TVP of at least 20 units from procurement; Goal 2 (g_2) a total procurement cost less than 288 million US dollars; Goal 3 (g_3) a minimal rate of defective machinery (less than 0.04) received from the vendor; and Goal 4 (g_4), for implementing a differentiation strategy (i.e., quality leadership), maintaining a current procurement level of fewer than 35 units. The quantity for these goals covers two choices; one or a proportion of both can be accepted. The AGHS company manager must determine the correct model and quantity of an aircraft towing truck to achieve the optimal result. Importing aircraft towing trucks entails expenses. To economize, at least $D = 30$ units of the aircraft towing truck should be selected. Consequently, certain constraints are added to the model to guarantee that these conditions are satisfied. Table 2 lists the coefficient and goal values for solving the MAGP problem.

Please insert Table 2 here

The MAGP model's notation is introduced as follows:

Indices:

i for goals

l for aspiration levels

k for segments

j for decision variables

Variables:

x_j decision variable

x_{jk} part of the j th decision variable in the k th segment

s_{jk} coefficient for the j th decision variable and the k th segment

Z_l coefficient for the l th aspiration level

d_i^+ positive deviation from the i th goal target value

d_i^- negative deviation from the i th goal target value

Parameters:

n number of goals

m number of decision variables

u number of aspiration levels for goal

h_j number of segments for the j th decision variable

C a constant that is related to the DM

Hence, the MAGP model can be expressed as follows:

$$\text{Minimize } \sum_{i=1}^n (d_i^+ + d_i^-) \quad (16)$$

Subject to

$$\sum_{j=1}^m \sum_{k=1}^{h_j} S_{ijk} - d_i^+ + d_i^- = \sum_{i=1}^u z_i g_{il}, \quad i=1,2,\dots,n \quad (17)$$

$$\sum_{k=1}^{h_j} x_{jk} = x_j, \quad j=1,2,\dots,m \quad (18)$$

$$\sum_{j=1}^m x_{jk} = C, \quad k=1,2,\dots,h_j \quad (19)$$

$$\sum_{j=1}^u z_i = 1 \quad (20)$$

$$d_i^+, d_i^- \geq 0, \quad i=1,2,\dots, n \quad (21)$$

3.4 Solution procedure

AGHSEVS is a problem involving multi-criteria, alternatives and evaluators; we developed a model for AGHSEVS in this study. The proposed model was designed on the basis of comparisons among AGHS equipment alternatives according to identified criteria. The AHP and fuzzy TOPSIS methods are used in the proposed model. The proposed model differs from equipment selection processes described in the relevant literature. The AHP is used to assign weights to the criteria to be used for AGHSEVS, and fuzzy TOPSIS is employed to prioritize the alternatives. The weights obtained from the AHP are included in the decision-making process by incorporating them into fuzzy TOPSIS computations, and the alternative priorities are determined by these weights. Thus, the weighting of criteria considered during decision-making and the evaluation of these criteria are performed simultaneously. Our proposed model substantially increases the efficiency of the decision-making process for AGHSEVS.

In Stage 1, criteria that will be used in the evaluation are determined and the decision hierarchy is formed. Following the approval of the decision hierarchy, the criterion weights are assigned by an expert AGHSEVS decision-making team in Stage 2, wherein pair-wise comparison matrices are formed. The team makes individual evaluations by using the scale provided in Table 1, to determine the elements values of pair-wise comparison matrices. AGHSEVS evaluation criteria ranks are determined using the fuzzy TOPSIS method in Stage 3. Linguistic values are used for the evaluation of AGHSEVS in this step. The membership functions of these linguistic values are displayed in Figure 1, and the triangular fuzzy numbers associated with these variables are displayed in Table 3. In Stage 4, we use LP and

GP approaches for AGHSEVS. Figure 2 illustrates the proposed model for AGHSEVS, comprising Stages 1 to 4 (Figure 2).

Please insert Figure 1 here

Please insert Figure 2 here

Please insert Table 3 here

According to the previously summarized fuzzy theory (Stages 1–3), the fuzzy TOPSIS steps can be outlined [10, 34]. In Stage 4 the LP, MCGP, and MAGP approaches are applied for AGHSEVS and the computational procedure is summarized as follows:

Step 1: Develop AGHSEVS criteria (expert team interview and survey).

Step 2: Identify necessary criteria for AGHSEVS and obtain AHP weight calculated at each level for overall scores.

Step 3: Select the linguistic values (x_{ij} , $i = 1, 2, \dots, n$, $J = 1, 2, \dots, k$) for alternatives with respect to criteria. The fuzzy linguistic rating (x_{ij}) preserves the property of ranges of normalized triangular fuzzy numbers belonging to [0, 1]; thus, normalization is not required.

Step 4: Calculate the weighted normalized fuzzy decision matrix.

Step 5: Identify positive-ideal (A^+) and negative ideal (A^-) solutions. These solutions are provided in the following equations:

$$A^+ = \left\{ \tilde{v}_1^+, \tilde{v}_2^+, \dots, \tilde{v}_i^+ \right\} = \left\{ \left(\max_j v_{ij} | i \in I' \right) \times \left(\min_j v_{ij} | i \in I'' \right) \right\}, i = 1, 2, \dots, n \quad j = 1, 2, \dots, k; \quad (22)$$

$$A^- = \left\{ \tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_i^- \right\} = \left\{ \left(\min_j v_{ij} | i \in I' \right) \times \left(\max_j v_{ij} | i \in I'' \right) \right\}, i = 1, 2, \dots, n \quad j =$$

$$1,2,\dots, k; \quad (23)$$

where I' is associated with benefit criteria and I'' is associated with cost criteria.

Step 6: Calculate the distance of each alternative from A^+ and A^- by using the following equations:

$$D_j^+ = \sum_{j=1}^n d(\tilde{v}_{ij}, v_i^+) \quad j = 1, 2 \dots J, \quad (24)$$

$$D_j^- = \sum_{j=1}^n d(\tilde{v}_{ij}, v_i^-) \quad j = 1, 2 \dots J, \quad (25)$$

Step 7: Calculate similarities to the ideal solution.

$$CC_j = \frac{D_j^-}{D_j^+ + D_j^-} \quad j = 1, 2 \dots J, \quad (26)$$

Step 8: Rank the preference order. Choose an alternative with maximum CC_j^+ or rank alternatives according to CC_j^+ in descending order. An alternative with the index CC_j approaching 1 indicates that the alternative is close to the fuzzy positive ideal reference point and far from the fuzzy negative ideal reference point. Note that a large value of the index CC_j indicates the favorable performance of an alternative A_j [5].

Step 9: Compare fuzzy TOPSIS and FWA left and right scores results.

Step 10: According to the closeness coefficients (Table 10) obtained from Step 8, build a LP model to determine the ideal vendors and their optimal order quantities. To select the optimal order quantities, the TVP should be maximized [41].

Step 11: According to the closeness indices obtained from Step 8, the LP method can be expressed as Eq. (27) to solve the AGHSEVS problem as follows:

$$\text{Max (TVP)} = 0.362X_1 + 0.350X_2 + 0.370X_3 + 0.324X_4 + 0.340X_5$$

$$0.362X_1 + 0.350X_2 + 0.370X_3 + 0.324X_4 + 0.340X_5 \leq 30$$

$$7.9X_1 + 8.9X_2 + 9.3X_3 + 9.5X_4 + 9.6X_5 \leq 288$$

$$5X_1 + 4X_2 + 6X_3 + X_4 + 2X_5 \leq 180$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 35$$

$$X_1 \leq 15; \quad \text{(vendor } EA_1 \text{ capacity constraint)} \quad (27)$$

$$X_2 \leq 10; \quad \text{(vendor } EA_2 \text{ capacity constraint)}$$

$$X_3 \leq 20; \quad \text{(vendor } EA_3 \text{ capacity constraint)}$$

$$X_4 \leq 30; \quad \text{(vendor } EA_4 \text{ capacity constraint)}$$

$$X_5 \leq 12; \quad \text{(vendor } EA_5 \text{ capacity constraint)}$$

$$X_1 \geq 0; X_2 \geq 0; X_3 \geq 0; X_4 \geq 0; X_5 \geq 0.$$

To solve an AGHSEVS problem, it is necessary to define the MCGP model according to the following goals. The manager of the AGHS company must determine the ideal vendors and their corresponding optimal quantities. According to sales records for the previous 5 years and sales forecasts for the company, the CEO and top managers of the company must establish four goals: Goal 1 (g_1), a TVP of at least 20 units from procurement (the more the better); Goal 2 (g_2), a total procurement cost less than 288 million US dollars (the less the better); Goal 3 (g_3), for achieved the procurement levels, a minimal rate of defective machinery (less than 0.04) received from the vendors (the less the better); Goal 4 (g_4), for implementing a differentiation strategy (i.e., quality leadership), a current procurement level of less than 35 units (the more the better). Variable coefficients in the model were calculated using a database comprising records of the preceding 5 years. The unit costs for the vendors EA_i ($i = 1, \dots, 5$) are 7.9, 8.9, 9.3, 9.5 and 9.6 million US dollars. According to the historical data, the rate of defective machinery from vendors EA_i ($i = 1, \dots, 5$) are 0.05, 0.04, 0.06, 0.01, and 0.02; delivery defects are set between 0.02 and 0.04, and the capacities of

the five candidate vendors EA_i ($i = 1, \dots, 5$) are 15, 10, 20, 30, and 12 units. The functions and parameters related to the AGHSEVS problem are listed as follows:

$$f_1(x) = 0.362X_1 + 0.350X_2 + 0.370X_3 + 0.324X_4 + 0.340X_5 \geq 20 \text{ and } \leq 30 \quad (g_1: \text{TVP goal, the more the better})$$

$$f_2(x) = 7.9X_1 + 8.9X_2 + 9.3X_3 + 9.5X_4 + 9.6X_5 \geq 276 \text{ and } \leq 288 \quad (g_2: \text{cost goal, the less the better; i.e. } \$7.9 \times 30 \text{ units} = \$276; \$9.6 \times 30 \text{ units} = \$288)$$

$$f_3(x) = 0.05X_1 + 0.04X_2 + 0.06X_3 + 0.01X_4 + 0.02X_5 \leq 1.8 \quad (g_3: \text{delivery defect rate goal, the less the better; i.e., } 0.06 \times 30 \text{ units} = 1.8)$$

$$f_4(x) = X_1 + X_2 + X_3 + X_4 + X_5 \geq 30 \text{ and } \leq 35 \quad (g_4: \text{procurement level goal, the more the better})$$

$$\text{Max (TVP)} = 0.362X_1 + 0.350X_2 + 0.370X_3 + 0.324X_4 + 0.340X_5$$

Subject to:

$$X_1 + X_2 + X_3 + X_4 + X_5 = 30 \quad (\text{demand constraint})$$

$$5X_1 + 4X_2 + 6X_3 + X_4 + 2X_5 \leq 180 \quad (\text{equipment quality constraint})$$

$$7.9X_1 + 8.9X_2 + 9.3X_3 + 9.5X_4 + 9.6X_5 \leq 288 \quad (\text{budgeting constraint})$$

$$X_1 \leq 15 \quad (\text{vendor } EA_1 \text{ capacity constraint})$$

$$X_2 \leq 10 \quad (\text{vndor } EA_2 \text{ capacity constraint})$$

$$X_3 \leq 20 \quad (\text{vendor } EA_3 \text{ capacity constraint}) \quad (28)$$

$$X_4 \leq 30 \quad (\text{vendor } EA_4 \text{ capacity constraint})$$

$$X_5 \leq 12 \quad (\text{vendor } EA_5 \text{ capacity constraint})$$

The following notation is defined to formulate the model:

Indices:

i 1,2,..., n index of vendors;

j 1,2,..., J index of deviation corresponding to the goals

t 1,2,..., T index of deviation corresponding to the multiple criteria

Parameters:

C_i cost of material of vendor i
 O_i order cost of vendor i
 CC_i closeness coefficient of vendor i
 V value of purchasing budget
 d_j^+, d_j^- maximum and minimum deviation of goal j
 e_t^+, e_t^- maximum and minimum deviation of $|y_t - g_{i,\max/\min}|$

q_i rate of delivery defects of vendor i
 p_i rate of delivery delay number of vendor i
 Q maximum acceptable rate of delivery defects
 P maximum acceptable rate of delivery delay number
 D demand
 S_i capacity of vendor i

Decision variables:

X_i order quantity of vendor i
 y_i binary integer $\begin{cases} 1 & \text{if the order is offered by vendors } i \\ 0 & \text{otherwise} \end{cases}$

According to the closeness indices obtained from Step 6, the MCGP method can be expressed as Eq. (29) to select the optimal equipment vendor.

$$\text{Min } d_1^+ + d_1^- + d_2^+ + d_2^- + d_3^+ + d_3^- + e_1^+ + e_1^- + e_2^+ + e_2^- + e_3^+ + e_3^-$$

$$\text{TVP} = 0.362X_1 + 0.350X_2 + 0.370X_3 + 0.324X_4 + 0.340X_5$$

$$f_1 = 0.362X_1 + 0.350X_2 + 0.370X_3 + 0.324X_4 + 0.340X_5$$

$$f_1 \geq 20; \quad f_1 \leq 30$$

$$f_2 = 7.9X_1 + 8.9X_2 + 9.3X_3 + 9.5X_4 + 9.6X_5$$

$$f_2 \geq 276; \quad f_2 \leq 288$$

$$f_3 = 0.05X_1 + 0.04X_2 + 0.06X_3 + 0.01X_4 + 0.02X_5$$

$$f_3 >= 1.2; \quad f_3 <= 1.8 \quad (29)$$

$$f_4 = X_1 + X_2 + X_3 + X_4 + X_5$$

$$f_4 >= 30; \quad f_4 <= 35$$

$$(0.362X_1 + 0.350X_2 + 0.370X_3 + 0.324X_4 + 0.340X_5)b_1 - d_1^+ + d_1^- = y_1 b_1$$

$$y_1 - e_1^+ + e_1^- = 20$$

$$y_1 >= 20$$

$$y_1 <= 35$$

$$(7.9X_1 + 8.9X_2 + 9.3X_3 + 9.5X_4 + 9.6X_5)b_2 - d_2^+ + d_2^- = y_2 b_2$$

$$y_2 >= 276$$

$$y_2 <= 288$$

$$(0.05X_1 + 0.04X_2 + 0.06X_3 + 0.01X_4 + 0.02X_5)b_3 - d_3^+ + d_3^- = y_3 b_3$$

$$y_3 - e_2^+ + e_2^- = 1.2$$

$$y_3 >= 1.2$$

$$y_3 <= 1.8$$

$$(X_1 + X_2 + X_3 + X_4 + X_5)b_4 - d_4^+ + d_4^- = y_4 b_4$$

$$y_4 - e_3^+ + e_3^- = 30$$

$$y_4 >= 30$$

$$y_4 <= 35$$

$$b_1 = b_2 + b_3 + b_4$$

$$b_1 + b_2 + b_3 + b_4 = 1$$

$$X_1 <= 15$$

$$X_2 <= 10$$

$$X_3 <= 20$$

$$X_4 <= 30$$

$$X_5 <= 12$$

$$X_1 >= 0; X_2 >= 0; X_3 >= 0; X_4 >= 0; X_5 >= 0;$$

$$d_1^+ >= 0; d_1^- >= 0; d_2^+ >= 0; d_2^- >= 0; d_3^+ >= 0; d_3^- >= 0; d_4^+ >= 0; d_4^- >= 0$$

$$e_1^+ >= 0; e_1^- >= 0; e_2^+ >= 0; e_2^- >= 0; e_3^+ >= 0; e_2^- >= 0.$$

Step 12: Using the MCGP method can be expressed as Eqs. (28) and (29) to select the optimal equipment vendor.

Step 13: Using the MAGP method can be expressed as Eq. (30) to select the optimal equipment vendor.

$$\text{Min } d_1^+ + d_1^- + d_2^+ + d_2^- + d_3^+ + d_3^-$$

$$\text{TVP} = 0.362X_1 + 0.350X_2 + 0.370X_3 + 0.324X_4 + 0.340X_5$$

$$f_1 = 0.362X_1 + 0.350X_2 + 0.370X_3 + 0.324X_4 + 0.340X_5$$

$$f_2 = 7.9X_1 + 8.9X_2 + 9.3X_3 + 9.5X_4 + 9.6X_5$$

$$f_3 = 0.05X_1 + 0.04X_2 + 0.06X_3 + 0.01X_4 + 0.02X_5$$

$$f_4 = X_1 + X_2 + X_3 + X_4 + X_5 \quad (30)$$

$$0.362X_1 + 0.350X_2 + 0.370X_3 + 0.324X_4 + 0.340X_5 - d_1^+ + d_1^- = 20Z_1 + 30Z_2$$

$$7.9X_1 + 8.9X_2 + 9.3X_3 + 9.5X_4 + 9.6X_5 - d_2^+ + d_2^- = 276Z_1 + 288Z_2$$

$$0.05X_1 + 0.04X_2 + 0.06X_3 + 0.01X_4 + 0.02X_5 - d_3^+ + d_3^- = 120Z_1 + 180Z_2$$

$$X_1 + X_2 + X_3 + X_4 + X_5 - d_4^+ + d_4^- = 30Z_1 + 35Z_2$$

$$X_1 <= 15 \quad (\text{vendor } EA_1 \text{ capacity constraint})$$

$$X_2 <= 10 \quad (\text{vendor } EA_2 \text{ capacity constraint})$$

$$X_3 <= 20 \quad (\text{vendor } EA_3 \text{ capacity constraint})$$

$$X_4 <= 30 \quad (\text{vendor } EA_4 \text{ capacity constraint})$$

$$X_5 <= 12 \quad (\text{vendor } EA_5 \text{ capacity constraint})$$

$$Z_1 + Z_2 = 1$$

$$Z_1 > = 0; Z_2 > = 0$$

$$X_1 > = 0; X_2 > = 0; X_3 > = 0; X_4 > = 0; X_5 > = 0$$

$$d_1^+ > = 0; d_1^- > = 0; d_2^+ > = 0; d_2^- > = 0; d_3^+ > = 0; d_3^- > = 0; d_4^+ > = 0; d_4^- > = 0.$$

Step 14: Compare the results of two GP models for AGHSEVS.

4. Case Application

The objective of this section is to illustrate the model by using a realistic application for an AGHS company—Taoyuan International Airport Services Co., Ltd. (TIAS), which is a joint-venture ground handling service company 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 forwarders at Taoyuan Airport. TIAS is the first ground handler in Taiwan to acquire ISO 9001 accreditation from an internationally recognized quality management systems aimed at maintaining high-quality service standards. In addition, TIAS, as a member of the International Air Transport Association Ground Handling Council, keeps pace with international ground handling industry developments and is committed to providing superior ground handling services. In 2013, Taoyuan airport provided ground handling services for 194,239 flights, 30,701,987 passengers, and 1,571,814,282 tons of cargo. Currently, TIAS has 1028 units of vehicular and 4,658 units of non-vehicular ground handling equipment.

The aim of this research was to evaluate alternative AGHSEVS problems and to help the DMs at AGHS companies meet purchasing requirements. However, it is difficult to select the most suitable equipment, because characteristics vary. For a real-world application, an expert AGHSEVS decision-making team was formed comprising two airport ground handling service department vice presidents and four

senior technical supply and maintenance managers at TIAS. All criteria used in the model were determined in advance by the decision-making team for obtaining criterion weights.

4.1 Identification of Criteria for AGHSEVS

Criteria considered in the selection of airport ground handling equipment were determined by the expert AGHSEVS decision-making team. Professional experience was utilized by the team in the determination of important criteria. Explanations of important criteria and their definitions are provided in Table 4 [4, 6, 10, 41].

Please insert Table 4 here

Following the determination of criteria, AGHSEVS processes under development or in use were investigated, and the expert AGHSEVS decision-making team determined all criteria on the basis of the needs of the company. The six criteria were equipment quality (EC_1), safety mechanisms (EC_2), maintenance (EC_3), technical transfer and mechanic training (EC_4), quick supply after sales and technical services and cooperative relationship (EC_5), and the reasonableness of the price (EC_6). These criteria were used to develop the decision hierarchy, which was established accordingly. A decision hierarchy, structured by the team, and related criteria are displayed in Figure 3.

Please insert Figure 3 here

4.2 Calculate of Criterion Weights

After developing the decision hierarchy, criterion weights were computed using the AHP method. In this phase, experts on the team developed the individual pair-wise comparison matrix; all scales used in the pair-wise comparison matrix are provided in Table 1. The geometric means of these values were determined to obtain the pair-wise comparison matrix that achieved a consensus among team members (Table 5).

Please insert Table 5 here

Please insert Table 6 here

The outcomes (Table 6) were obtained from computations based on the pair-wise comparison matrix (Table 4). EC_2 , EC_4 and EC_6 were determined as the most essential criteria for AGHSEVS, according to the AHP. The CR of the pair-wise comparison matrix was computed as $0.055 < 0.1$. Thus, the weights were shown to be consistent, and consequently, they were used in the subsequent selection procedures.

4.3 Evaluation of Alternatives and Determining the Rank

During Step1, when alternatives were evaluated, team members were asked to establish the decision matrix by comparing alternatives under each criterion separately. A fuzzy evaluation matrix, established by evaluating the choice of ground handling equipment according to linguistic variables in Tables 4 and 7 was composed of triangular fuzzy numbers equivalent to linguistic variables. In Step 1, the fuzzy evaluation matrix was determined using the criterion weights computed through the AHP (Table 6). In Step 2, the weighted evaluation matrix was developed using Eq.(4). The resulting fuzzy weighted decision matrix is displayed in Table 8. In Table 9, the elements $v_{ij}, \forall i, j$ are normalized by positive triangular fuzzy numbers and their scopes belong to a closed interval $[0, 1]$. For AGHSEVS, we used the aforementioned definition of the fuzzy positive-ideal solution and fuzzy negative-ideal solution as $\tilde{v}_i^+ = (1,1,1)$ and $\tilde{v}_i^- = (0,0,0)$ for the benefit criterion, and $\tilde{v}_i^+ = (0,0,0)$ and $\tilde{v}_i^- = (1,1,1)$ for the cost criterion. Step 3, Eqs. (5) and (6). For AGHSEVS, EC_2 and EC_6 were cost criteria, whereas the remaining criteria were benefit criteria. In Step 3, the distance of each alternative from D^+ and D^- could be calculated using Eqs. (7) and (8). Step 4 involved identifying an ideal solution according to the similarity by using Eq. (9). Detailed illustrations of the method are

provided by Dağdeviren et al. [10]. Similar calculations were conducted for the other alternatives, and the outcome of the fuzzy TOPSIS method is provided in Table 8. Based on CC_j values, the ranking of the alternatives in descending order is EA_3 , EA_1 , EA_2 , EA_5 and EA_4 . The results of the proposed model indicated that EA_3 is the most suitable alternative, with a CC value of 0.370. The criteria have equal priorities in this case, and the CC_j values obtained are presented in Table 10.

Based on un-weighted CC_j values, the ranking of the alternatives in descending order is EA_3 , EA_1 , EA_2 , EA_5 and EA_4 . The most suitable alternative is the same as that for the weighted ranking. A detailed discussion of fuzzy TOPSIS methods is provided by Dağdeviren et al. [10].

Please insert Table 6~10 here

For validation, a comparing was performed with the FWA left and right scores, and the ranking is EA_3 , EA_5 , EA_1 , EA_2 and EA_4 . These results are similar to the fuzzy TOPSIS results (EA_3 , EA_1 , EA_2 , EA_5 and EA_4 ; Table 11).

Please insert Table 11 here

4.4 Comparing Solutions for the LP, MCGP and MAGP models

The LP, MCGP, and MAGP models were solved using the Lingo 11.0 software package. For the LP model, the ideal vendor and its optimal quantities were calculated as: (g_1) $TVP = 12.17$, $(g_2) f_2 = 288$, $(g_3) f_3 = 1.84$, $(g_4) f_4 = 33.22$, $X_1 = 15$, $X_2 = 0$, $X_3 = 18$, $X_4 = 0$, and $X_5 = 0$. For the MCGP model, the ideal vendor and its optimal quantities were calculated as: (g_1) $TVP = 12.16$, $(g_2) f_2 = 288$, $(g_3) f_3 = 1.80$, $(g_4) f_4 = 33.33$, $X_1 = 15$, $X_2 = 3$, $X_3 = 16$, $X_4 = 0$, and $X_5 = 0$. For the MAGP model, the ideal vendor and its optimal quantities were calculated as (g_1) $TVP = 11.69$, $(g_2) f_2 = 276$, $(g_3) f_3 = 1.77$, $(g_4) f_4 = 31.93$, $X_1 = 15$, $X_2 = 0$, $X_3 = 17$, $X_4 = 0$, and $X_5 = 0$. This indicated that X_3 (EA_3) is the ideal vendor with the maximum purchase quantity.

5. Conclusion and Implications

AGHSEVS is a critical problem that affects ramp work safety conditions in AGHS companies. This study presents a systematic framework for assessing AGHSEVS and used triangular fuzzy numbers to express linguistic values and account for the subjective judgments of evaluators who participate in group decisions. Fuzzy TOPSIS methods can use linguistic variables to assess the importance of criteria and to evaluate each alternative with respect to each criterion. These linguistic variables were transformed into triangular fuzzy numbers, and a fuzzy decision matrix was constructed. Next, a normalized fuzzy decision matrix and a weighted normalized fuzzy decision matrix were formed. The fuzzy positive ideal situation and the fuzzy negative ideal situation were then defined, and the distances of each alternative to the positive and negative ideal situations were calculated. Finally, the correspondence coefficient of each alternative was calculated separately. According to the correspondence coefficients of the five alternatives, the ranking order of the five alternatives was determined to be EA_3 , EA_1 , EA_2 , EA_5 , and EA_4 in descending order. The results of the proposed model indicated that EA_3 is the optimal alternative. Unweight CC_j values and weighted CC_j values indicated the same result with respect to weighted ranking outcomes. FWA left and right score weights ranked the result similarly to the fuzzy TOPSIS method.

5.1 LP Model Results Compared with MAGP and MCGP Models Results

To verify the LP model and find the most suitable solution results, we integrated MCDM into the LP model, and two GP models were developed as experimental methods for use in AGHSEVS. The Lingo 11.0 software package was used to solve the LP model, and the results listed as follows: (g_1): $TVP=12.17$ (the highest value),

(g_2): $f_2 = 288$, (g_3): $f_3 = 1.84$, (g_4): $f_4 = 33.22$, $X_1 = 15$, $X_2 = 0$, $X_3 = 18$, $X_4 = 0$, and $X_5 = 0$. All four goals were achieved in the MCGP model. The MAGP model also achieved all four low price and quality goals (g_1 : $TVP = 11.69$, g_2 : $f_2 = 276$, g_3 : $f_3 = 1.77$, g_4 : $f_4 = 31.93$). The MAGP model indicated that purchases are made more frequently in Hong Kong and the United States than in the other countries. (i.e., X_1 : Hong Kong = 15; X_2 : Japan = 0; X_3 : United States = 17; X_4 : France = 0. X_5 : Germany = 0).

5.2 Management Implications

Our AGHSEVS model provides four contributions: (i) The AGHSEVS model can help DMs identify appropriate AGHS equipment and enable purchasing managers to easily select the ideal AGHSEVS on the basis of criteria such as equipment quality, technical transfer and mechanic training, and reasonableness of the price. (ii) The systematic new evaluation procedure can help AGHS company managers make optimal decisions for AGHSEVS. (iii) The AGHSEVS model successfully solves the AGHSEVS problem by considering both qualitative and quantitative methods. (iv) The model can be used, with slight modifications, in other decision-making problems in AGHS companies and in other countries.

For future studies, other multi-criteria methods, such as the fuzzy PROMETHEE and ELECTRE methods can be used to solve AGHSEVS problems. Additional, others mathematical models such as the AHP-QFD model [36] can be combined with the model proposed here. This can potentially improve our proposed model, which is the goal of our future research.

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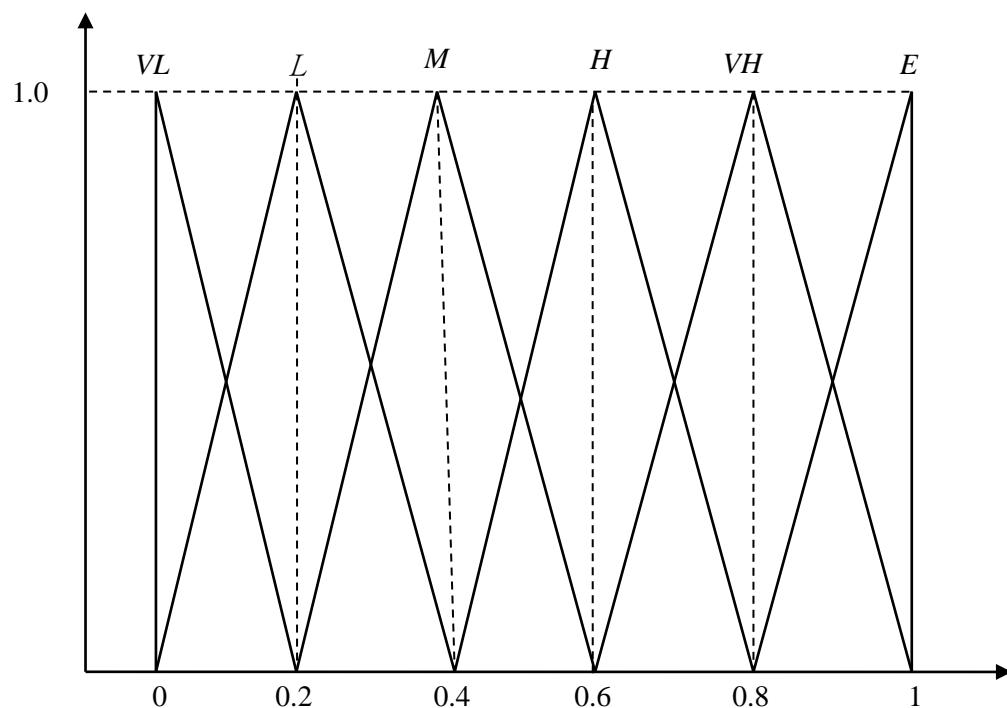


Figure 1: Membership functions of linguistic values for criteria

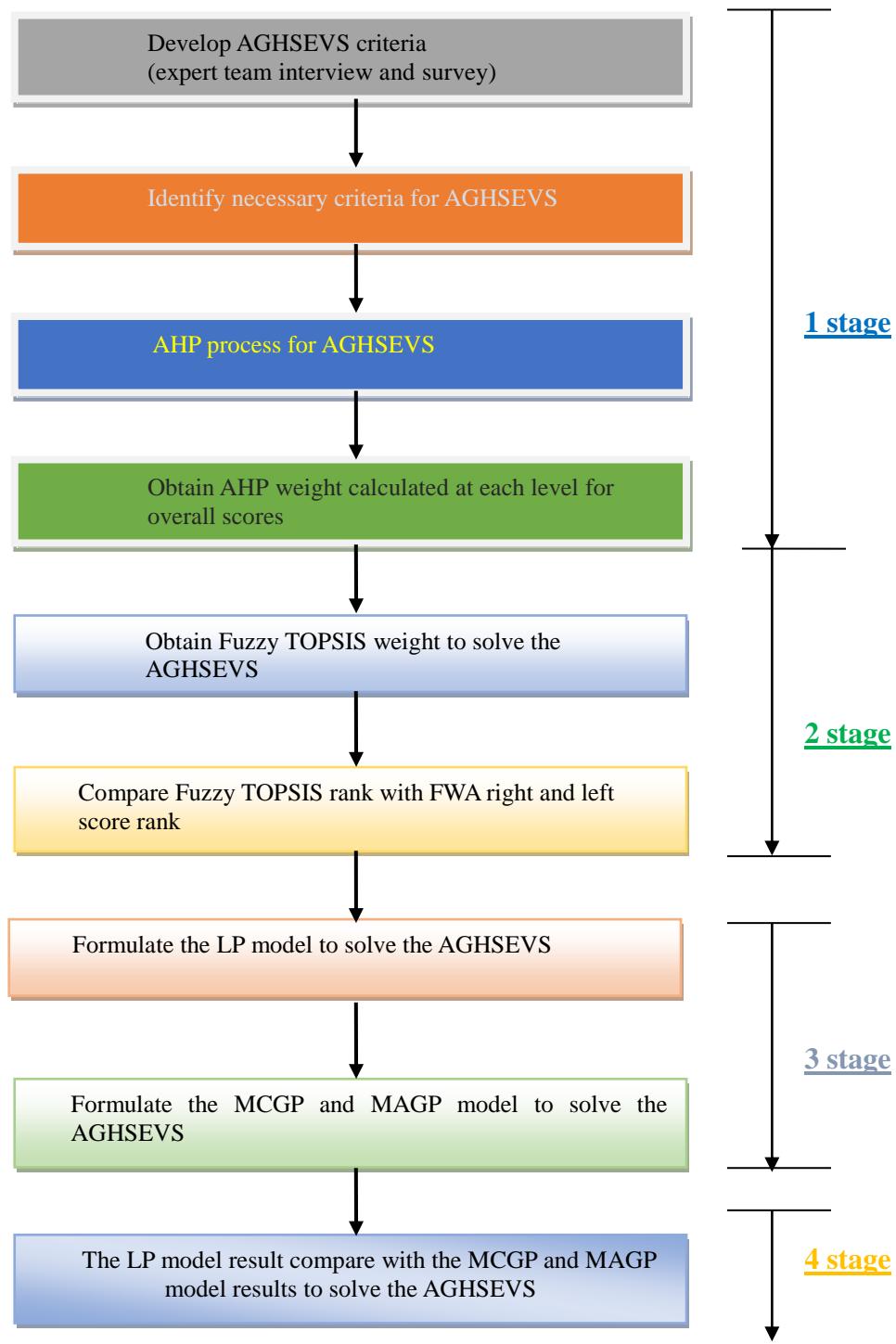


Figure 2: Schematic diagram of the proposed model for AGHSEVS

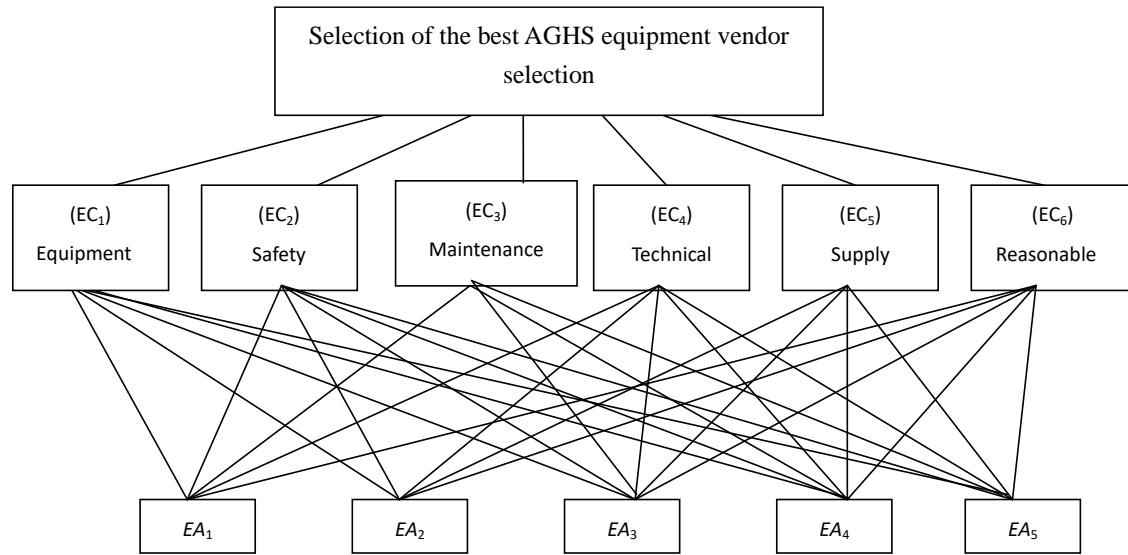


Figure 3: The decision hierarchy of AGHSEVS

Table 1 Description of nine-point intensity of importance scale

Intensity of importance	Definition meaning
1	Equally important
3	Moderately more important
5	Strongly more important
7	Very strongly more important
9	Extremely more important
2,4,6,8	Intermediate values

Table 2 Coefficient and goal values for MAGP model

Coefficient segments of variable					Choice	
X_1	X_2	X_3	X_4	X_5	Choice value	Goal
0.362	0.35	0.37	0.324	0.340	20, 30	TVP
7.9	8.9	9.3	9.5	9.6	276, 288	Cost(Price)
0.05	0.04	0.06	0.01	0.02	1.2, 1.8	Delivery defect rate
1	1	1	1	1	30, 35	Procurement level
Hong Kong	Japan	United States	France	Germany		Manufacture areas

Table 3 Linguistic values and associated fuzzy numbers

Linguistic values	Fuzzy numbers
Very low (VL)	(0, 0, 0.2)
Low (L)	(0, 0.2, 0.4)
Medium (M)	(0.2,0.4,0.6)
High (H)	(0.4,0.6,0.8)
Very high (VH)	(0.6,0.8, 1)
Excellent (E)	(0.8, 1, 1)

Table 4 AGHS equipment evaluation criteria and its definitions

Equipment Criteria	Definition of Importance
(EC ₁) Equipment quality	Good equipment quality control mean-time-between-failures (MTBF) Good operation in airport work environment
(EC ₂) Safety mechanisms	Provides a safety mechanism for operators. Provide building equipment safety mechanism to prevent unexpected AGHS equipment accidents. Use airport ground handling equipment standards for reliability
(EC ₃) Maintenance	Availability and maintainability. On-line control process systems. Direct spare-parts supply mean-time-to repair(MTTR) Provide repair guarantee support
(EC ₄) Technical transfer and mechanic training	Provide technical information sharing Provide technical mechanic training Adequate number of experience consultants Continuous improvement programs
(EC ₅) Supply after sales quick technical services and cooperative relationship	Provide after sales good quality of service and good relationship. Continuous improvement programs.
(EC ₆) Reasonable price	Limited project budget. Limited annual maintenance budget.

Table 5 the pair-wise comparison matrix criteria

	EC ₁	EC ₂	EC ₃	EC ₄	EC ₅	EC ₆
EC ₁	1.0	0.2	0.3	0.4	0.2	0.6
EC ₂	0.5	1.0	3.4	1.9	2.3	2.3
EC ₃	2.4	0.4	1.0	0.3	0.4	0.4
EC ₄	0.4	0.5	3.2	1.0	1.5	2.4
EC ₅	1.9	0.4	2.1	0.5	1.0	1.9
EC ₆	1.8	2.9	2.3	0.3	2.8	1.0

Table 6 Results obtained with AHP

Equipment Criteria	Weights(w)	λ_{\max} , CI, RI	CR
EC_1	0.067	$\lambda_{\max} = 6.303$	
EC_2	0.277		
EC_3	0.114	CI = 0.060	0.050
EC_4	0.195		
EC_5	0.167	RI = 1.24	
EC_6	0.179		

Table 7 Fuzzy evaluation matrix for the selection airport ground handling equipment

	EC_1	EC_2	EC_3	EC_4	EC_5	EC_6
A_1	Excellent	Low	Medium	Very high	Medium	High
A_2	High	Medium	Very high	High	High	Very high
A_3	Very high	Medium	High	Excellent	High	Medium
A_4	Low	Very high	Excellent	Medium	Medium	High
A_5	Very high	High	Low	Very high	Very high	Excellent
A_1	(0.8, 1, 1)	(0,0.2,0.4)	(0.2,0.4,0.6)	(0.6, 0.8, 1)	(0.2,0.4,0.6)	(0.4,0.6,0.8)
A_2	(0.4,0.6,0.8)	(0.2,0.4,0.6)	(0.6,0.8, 1)	(0.4,0.6,0.8)	(0.4,0.6,0.8)	(0.6,0.8, 1)
A_3	(0.6, 0.8, 1)	(0.2,0.4,0.6)	(0.4,0.6,0.8)	(0.8, 1, 1)	(0.4,0.6,0.8)	(0.2,0.4,0.6)
A_4	(0, 0.2, 0.4)	(0.6,0.8, 1)	(0.8, 1, 1)	(0.2,0.4,0.6)	(0.2,0.4,0.6)	(0.4,0.6,0.8)
A_5	(0.6,0.8, 1)	(0.4,0.6,0.8)	(0, 0.2, 0.4)	(0.6,0.8, 1)	(0.6,0.8, 1)	(0.8, 1, 1)
*Weight	0.067	0.277	0.114	0.195	0.167	0.179

Note: * AHP Weight

Table 8 Weighted evaluations for the alternative airport ground handling equipment

	EC_1	EC_2	EC_3	EC_4	EC_5	EC_6
A_1	(0.054,0.067,0.067)	(0.000,0.055,0.111)	(0.023,0.046,0.068)	(0.117,0.156,0.195)	(0.033,0.067,0.100)	(0.072,0.107,0.143)
A_2	(0.027,0.040,0.054)	(0.055,0.111,0.166)	(0.068,0.091,0.114)	(0.078,0.117,0.156)	(0.067,0.100,0.134)	(0.107,0.143,0.179)
A_3	(0.040,0.054,0.067)	(0.055,0.111,0.166)	(0.046,0.068,0.091)	(0.156,0.195,0.195)	(0.067,0.100,0.134)	(0.036,0.072,0.107)
A_4	(0.000,0.013,0.027)	(0.166,0.222,0.277)	(0.091,0.114,0.114)	(0.039,0.078,0.117)	(0.033,0.067,0.100)	(0.072,0.107,0.143)
A_5	(0.040,0.054,0.067)	(0.111,0.166,0.222)	(0.000,0.023,0.046)	(0.117,0.156,0.195)	(0.100,0.134,0.167)	(0.143,0.179,0.179)
A^+	$\tilde{V}_1^+ = (1,1,1)$	$\tilde{V}_2^+ = (0,0,0)$	$\tilde{V}_3^+ = (1,1,1)$	$\tilde{V}_4^+ = (1,1,1)$	$\tilde{V}_5^+ = (1,1,1)$	$\tilde{V}_6^+ = (0,0,0)$
A^-	$\tilde{V}_1^- = (0,0,0)$	$\tilde{V}_2^- = (1,1,1)$	$\tilde{V}_3^- = (0,0,0)$	$\tilde{V}_4^- = (0,0,0)$	$\tilde{V}_5^- = (0,0,0)$	$\tilde{V}_6^- = (1,1,1)$

Table 9 Fuzzy TOPSIS results (weighted) CC_j

Alternatives	D^+	D^-	CC_j
EA_1	3.852	2.182	0.362
EA_2	3.919	2.108	0.350
EA_3	3.793	2.232	0.370
EA_4	4.075	1.953	0.324
EA_5	3.975	2.048	0.340

Table 10 Fuzzy TOPSIS weighted and unweight (i.e., no AHP weighted) rankings

Rank	Weighted CC_j	Weighted ranking	Un-weight CC_j	Un-weighted ranking
1	0.370	EA_3	0.669	EA_3
2	0.362	EA_1	0.608	EA_1
3	0.350	EA_2	0.560	EA_2
4	0.340	EA_5	0.508	EA_5
5	0.324	EA_4	0.432	EA_4

Table 11 Fuzzy average weighted left and right scores rank result

Vendor number	<i>L</i> Value	<i>R</i> Value	FWA Average Value	Rank
<i>EA</i> ₁	0.264	0.587	0.425	3
<i>EA</i> ₂	0.318	0.426	0.372	4
<i>EA</i> ₃	0.318	0.593	0.456	1
<i>EA</i> ₄	0.318	0.418	0.368	5
<i>EA</i> ₅	0.377	0.474	0.426	2