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Analytic Hierarchy Process-Based Airport Ground Handling Equipment Purchase Decision Model

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Abstract: The Airport ground handling services (AGHS) equipment supplier provider selection requires a safety guarantee in terms of the daily operations AGHS provider. AGHS providers seek to avoid aircraft damage and airline delays and ensure the provision of reliable and high-quality services. The primary objective of this paper was to develop purchasing decision model of the analytic hierarchy process (AHP), AHP-fuzzy linear programming (FLP), and AHP-Taguchi loss function (TLF) multi-choice goal programming (MCGP) purchase decision models to help the AGHS purchasing managers in selecting the best AGHS equipment supplier provider. The constructed models were assessed, and results obtained for the AHP-FLP and AHP-TLF-MCGP models were compared. We conducted a real-world example of supplier selection by an AGHS company by using the proposed models. The proposed model provides useful information and has practical value for AGHS providers.

Keywords: equipment purchase decision; analytic hierarchy process; Taguchi loss function; fuzzy linear programming; multi-choice goal programming



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1. Introduction

The Airport ground handling service (AGHS) companies are responsible for varied ground handling service activities. Ground handling operations can be categorized as either terminal or airside operations. In this study, we focused on decision models for identifying the best suppliers of equipment for airside operations. Ramp handling, a major task performed by AGHS companies [1], involves aircraft loading and unloading operations as well as passenger, crew, baggage, and freight (e.g., mail) transport between aircraft and terminal buildings [2]. Ramp handling classified as a logistics service, and it be offered by a third-party service provider ground handler service company (i.e., the AGHS company), an airline company (self-handling), or a ramp handling company within an airport [3,4].

AGHS duties are difficult for ground handlers whose work safety relies on technologically advanced equipment. Furthermore, AGHS companies experience anxieties with the ground handler service performance and quality of equipment. In addition, purchasing managers at AGHS companies select equipment suppliers with favorable reputations, and they have two reasons for doing so. First, the use of high-quality AGHS equipment can increase the safety of ground handling operations. Second, such supplier performs quality assurance, indicating that their equipment is of a high quality, and this can inspire confidence in AGHS providers and the airlines that pay for such services. AGHS equipment supplier selection (AGHSESS) problem has a marked effect on AGHS quality, and it is influenced by several factors. Such factors include a supplier's manufacturing performance, the supplier's industry reputation, and the supplier's produce quality and price [5]. In general, multiple-criteria decision-making (MCDM) methods assistance decision-makers (DMs) make estimations related to a list of options. Depending on the purchasing conditions,

certain criteria have different levels of importance, thus necessitating criteria weighting [6,7]. Optimal AGHSESS is an MCDM problem [8]. AGHSESS problem participate a vital role in the decision-making process of an AGHS provider; however, optimal AGHSESS is a time wasting and difficult procedure that requires relevant experience and an understanding of the industry, and this task can be difficult for AGHS purchasing managers [9]. This study motivation has proposed an effective decision model for AGHSESS in order to enable DMs make decisions in scenarios that involve the consideration of numerous factors and the assessment of a substantial body of information and records [10]. The subsequently section presents a review of the related value of literature.

2. Literature Review

Supplier selection (SC) is extensively discussed in the literature. For example, Monczka et al. [11] suggested the use of factor analysis for assessing the value of suppliers. Vonderembse and Tracey [12] conducted a study involving 268 purchasing managers to determine their supplier selection criteria when suppliers constantly endeavored to improve their products. Suppliers can obtain information on buyer requirements, traditions, and decision-making patterns, and this can help them alter and better apply their resources. Such information is advantageous to suppliers [12], because it enables them to clearly understand customer needs. Bhutta and Huq [13] highlighted two main approaches that managers can use to construct decision criteria while considering supplier choices; one of the approaches involves considering the total cost of ownership, and the other is based on a hierarchical procedure. Sarkis and Talluri [14] used an analytic network process (ANP) decision model to perform a strategic supplier selection.

Although the AGHSESS is an important consideration among AGHS providers, publications on this topic are limited. Some studies have provided useful information pertaining to equipment supplier evaluations. For example, Sevkli et al. [5] applied a mixed technique (e.g., AHP-fuzzy linear programming (FLP) model) to resolve the vendor choice problems. When the conventional AHP is used, AGHSESS is based on only price and reputation. Specifically, a buyer company must implement optimal supplier selection to increase their efficiency in response to uncertainty and resource constraints. Accordingly, the AHP-FLP technique is more useful than the conventional AHP techniques [7]. Goztepe and Kahraman [15] considered the military DM processes for battle-field operations and operations planning. Ordoobadi [16] combined the AHP and Taguchi loss function (TLF) to rank potential suppliers for outsourcing purposes. Furthermore, Liao and Kao [17] integrated AHP, TLF, and multi-choice goal programming (MCGP) models to resolve provider choice problems. Magdalena [18] combined the TLF and FLP to identify the optimal supplier in a given situation. By combining the TLF and AHP, Ordoobadi [19] provided an approach for ranking technology choices for achievement intentions. However, few investigations of AGHSESS and related techniques in practice have been published. To block this gap in the past literature, this paper applied an AHP-FLP and AHP-TLF-MGCP model in the context of a Taiwanese AGHS provider. Our main goal was to help the purchasing managers of such companies' use straightforward techniques to identify the most suitable equipment suppliers. For the sake of reducing the AHP and AHP-FLP model approaches drawbacks and reach precise results, we are using the AHP-TLF-MGCP model to validate of the AGHSESS problem. Our AHP-TLF-MGCP model can provide a valuable reference that allows DMs to set various desire levels for related equipment suppliers and buyers.

The rest of this manuscript is organized as follows: Section 2 summarizes the proposed methods; Section 3 details the proposed model for AGHSESS problems. In Section 4, presents findings related how to the use of the AHP-FLP and AHP-TLF-MGCP approaches to solve AGHSESS problems. We also explain the practical value of this approach in a real-world case. Lastly, conclusions and implications are presented in Section 5.

3. Methods

In this methods section, we explain how the AHP, AHP-FLP, and AHP-TLF-MGCP purchase decision models can be used to solve the aforementioned AGHSESS problem.

3.1. AHP Technique

The AHP technique is a judgment-based technique established by Saaty [20] for dealing with composite, and MCDM problems. The AHP is founded on three concepts: The formation of the model, a relative decision based on certain criteria, and a combination of the precedence. The AHP has been used to solve diverse MCDM problems [21–24].

Saaty [25] stated that in many real-world cases, the pair-wise decisions of DMs have several levels of ambiguity. Generally, the executive team tasked with AGHSESS is confident about the ranking of the assessment elements but unsure of whether the mathematical assessments related to such decisions are accurate. The traditional AHP-based approach to overcoming this issue is to introduce a distinct linguistic assessment of decisions. In preference to straight allocating numerical values to the comparison ratios, the AGHS equipment executive team selects a suitable linguistic expression that corresponds most to the decision options.

3.2. TLF Method

The TLF method for assessing loss as an outcome of a product does not meet any regulatory terms [26]. Loss calculation is conducted to quantitatively evaluate the loss of quality caused by inconsistencies between the specified quality and actual quality of a product.

In general, three styles of loss function are used to calculate Taguchi loss [27–29]. First, a two-sided loss function is used; in this function, a supposed value is the goal and deviation from either side of the goal is permitted provided that it remains within the speciation limits. In this study, quality loss functions were used to quantify the effect of AGHSESS tasks.

3.3. Fuzzy FLP Method

Bellman and Zadeh [30] proposed a fuzzy programming model for DM in the context of a fuzzy situation. Their method was used by Zimmermann [31] to solve FLP problems [10].

We used an AHP-weighted FLP model (hereafter referred to as AHP-FLP model) in our study to solve AGHSESS problems of practical importance to an AGHS provider in Taiwan. This work represents an attempt to overcome real-world obstacles encountered in the use of an AHP-FLP technique.

3.4. MCGP Approach

Scholars have devised many modified goal programming methods using MCGP. To recover the utility of goal programming (GP) methods, Chang [32] developed a model for resolve the multi-objective decision-making (MODM) problems using multi-choice aspiration levels (MCALs). Chang's proposal to solve MODM problems using MCALs differs considerably from a fuzzy goal programming approach in that their model incorporates membership functions (MFs) to address MODM problems with imprecise goal aspiration levels. The following equations address this issue based on a typical MCGP problem:

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

Subject to

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

$$y_i - e_i^+ + e_i^- = g_{i,\min} \quad i = 1, 2, \dots, n, \quad (3)$$

$$g_{i,\min} \leq y_i \leq g_{i,\max} \quad i = 1, 2, \dots, n, \quad (4)$$

$$d_i^+, d_i^-, e_i^+, e_i^- \geq 0, i = 1, 2, \dots, n \quad (5)$$

$X \in F$ where F is an achievable set and X has no symbol constraints.

Refer to the case regarding the managerial implications of constraints in [32].

4. Proposed Model

The proposed model is on the foundation of AHP-FLP methodology for solving AGHSESS problems. The model procedure is described as follows.

4.1. Format of the AHP-FLP Purchase Decision Model Process Based on AHP-FLP

The model for the AGHSESS problem and the AHP-FLP model involves three essential phases: (1) Identifying the criteria chosen in the purchase decision model, (2) conducting AHP calculations, (3) and making optimal decisions using the AHP-FLP approach this will help the AGHS provider. The entire AHP process is detailed in [5].

In this proposed model section, the general multi-purpose fuzzy model for AGHSESS is current in the tracking method [5,7,33,34]. The fuzzy multi-objective formulation for the aforementioned selection problems is derived as follows:

Obtain a vector X , where X is $[x_1, x_2, x_3, \dots, x_n]$ that exploits the AGHSESS goal utility function z_k with a number of m criteria [5]:

$$\text{Max } \tilde{z}_k = \sum_{i=1}^n (c_{ki} \times x_i) \geq \sim z_k^0 \quad k = 1, 2, 3, \dots, n \quad (6)$$

The following tracking constraints are applied:

$$\sum_{i=1}^n a_{ri} \times x_i \leq b_r \quad (7)$$

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

In this proposed model, \sim signifies the fuzzy situation. The symbol $\geq \sim$ denotes the fuzzified (i.e., unclear or fuzzy) edition of \geq and indicate adequately equipped or better. Z_k^0 is the rank that the DM desires to achieve.

All goal purpose values, \tilde{z}_k , are adjusted linearly from z_k^{\min} to z_k^{\max} . Such values may be treated similar to fuzzy numerals in relation to the linear membership function (LMF) as presented in Figure 1.

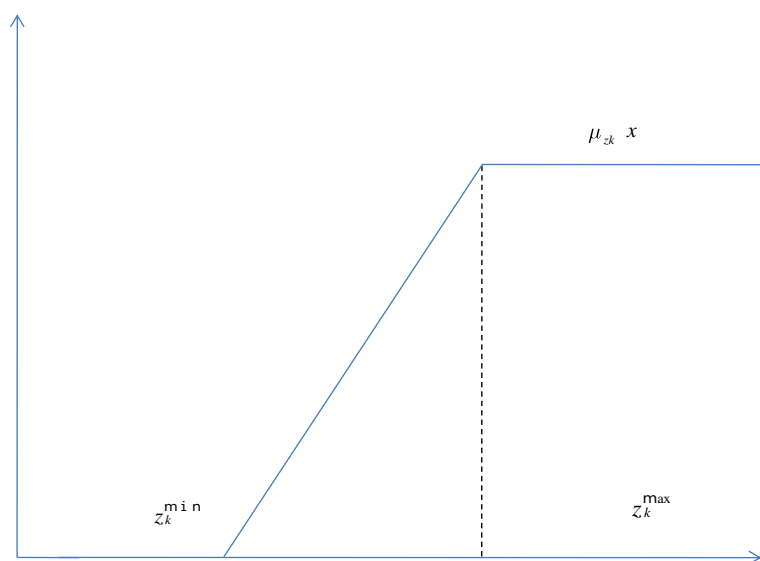


Figure 1. Maximizing objective function as fuzzy number.

As described in the aforementioned LMF, maximization aspirations (\tilde{z}_k) are given as follows:

$$\mu_{z1}(x) = \begin{cases} 1 & \text{for } z_k \geq z_k^{\max} \\ (z_k^{\max} - z_k(x)) / (z_k^{\max} - z_k^{\min}) & \text{for } z_k^{\min} < z_k < z_k^{\max} \\ 0 & \text{for } z_k \leq z_k^{\min} \end{cases} \quad (8)$$

The decision model presented in Equations (6) and (7) be present constructed using the weighted additive model, which is broadly used to address vector optimization problems; the essential idea is to use a single efficacy purpose to precise the general preferences of the DM to elucidate the significance of certain criteria [5,35]. In this methodology, all fuzzy MFs must be derived in terms of their relative weights, and subsequently, the derivation results must be added to obtain a linear weighted function.

$$\max \sum_{k=1}^m (w_k \times \lambda_k) \quad (9)$$

subject to:

$$\lambda_k \leq \mu_{zk}(x) \quad (10)$$

$$\lambda_k \in [0, 1] \text{ and } k = 1, 2, 3, \dots, n \quad (11)$$

$$\sum_{k=1}^m w_k = 1, w_k \geq 0 \quad (12)$$

$$x_i \geq 0, i = 1, 2, 3, \dots, m \quad (13)$$

where w_k and $\mu_{zk}(x)$ denote the resolution of the MF and the weighted coefficients that have a crucial relationship with the fuzzy objectives and membership functions.

In the third phased of the proposed approach, the AHP-FLP decision model helps the AGHS provider make optimal purchase decisions. The operating procedures of this AHP-FLP decision model are as follows:

- Step 1: An AGHSESS criterion is selected for determining the hierarchical construction for the choice of the finest supplier.
- Step 2: The team of experts and researchers conduct weight computation for the criteria at various hierarchical levels to determine the general achievements for each AGHS equipment supplier by conducting pairwise comparisons of the major decision criteria.
- Step 3: According to the criteria identified for related equipment selection, the AGHSESS purchase decision model is constructed.
- Step 4: Define the lower bound (z_k^{\min}) and upper bound (z_k^{\max}) multi-objective purchase decision problem is similar to a single-objective linear programming model.
- Step 5: z_k^{\min} and z_k^{\max} assessments are used to obtain the LMF for the criterion in Equation (8).
- Step 6: On the basis of the weighted additive model, we create the corresponding crisp typical of the fuzzy optimization problem using Equations (6)–(13).
- Step 7: We identify the best result vector X , which represents the expert decision on the unique purchase decision problem.
- Step 8: We compare the AHP and AHP-FLP models.
- Step 9: On the basis of the results of the AHP-FLP model, we construct the AHP-TLF-MCGP model to solve the AGHSESS problem according to Equations (1)–(5). The loss function, weighted Taguchi values, and normalized values derived in the calculation are summarized in Tables 1–12 (further details on the procedure are provided in [19]).
- Step 10: The results obtained using the AHP-FLP model and AHP-TLF-MCGP models are compared.

Table 1. Equipment supplier decision criteria.

Equipment Supplier Decision Criteria	Quality Guarantee Definition
Quality management	system (ISO/TS 16 Quality guarantee system(ISO/TS 16949/QS-9000/ISO 14001) policy and domestic quality inspections.
Production capacity and maintenance	Producing ability contain high-quality utilize of statistical process control (SPC), lean manufacturing and a “kanban” system. Supplier novelty abilities comprise hardware, software (CAD/CAE/CAM), information, works and skill. The fix and preservation examine sustains customer agreement.
Product warranty	Suppliers trail assurances and include an assessment procedure to define what forces enhancements in assurance expenses and buyer agreement
Provide technical transfer	The scientific compatibility of the overhaul, the substantial or the parts that are affording to the retail corporation is vital.
Good cooperative relationship and reputation	A durable and flourishing buyer/supplier association needs shared reliance and consideration The provider has a fine financial situation in the manufacturing
Reasonable parts price	The supplier provides reasonable parts prices.

Table 2. Criteria 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. Pair-wise comparison template criteria.

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

Table 4. Adjusted template [37].

	Quality	Maintenance	Warranty	Technical	Reputation	Price	(Weights Row Average)
Quality	0.141	0.121	0.214	0.120	0.167	0.148	0.152
Maintenance	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 evaluate assessment of suppliers with regard to all evaluation criteria. [38].

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
Row Average	0.151**	0.062	0.079	0.241	0.039	0.428	

Notes: 1. $0.395^* = 0.633 \times 0.151 = 0.096 + 0.077 \times 0.062 = 0.005 + 0.064 \times 0.079 = 0.005 + 0.057 \times 0.241 = 0.014 + 0.096 \times 0.039 = 0.004 + 0.633 \times 0.428 = 0.271$. 2. $0.151^{**} = 0.096 + 0.039 + 0.016$.

Table 7. Input data for airport ground handling service equipment supplier selection.

	Quality	Maintenance	Warranty	Technical	Reputation	Price
Supplier1 (x_1)	0.096	0.005	0.005	0.014	0.004	0.271
Supplier2 (x_2)	0.039	0.014	0.021	0.156	0.024	0.111
Supplier3 (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

Table 8. Dataset used for representing the utilities relationships.

Lower (z_k^{\min}) and Upper (z_k^{\max}) Bounds	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

Table 9. Decision-maker's (DM's) perception of supplier performance related to six criteria.

	Quality	Maintenance	Warranty	Technical	Reputation	Price
Supplier1	90	65	90	65	70	92
Supplier2	85	70	94	75	75	90
Supplier3	92	72	96	70	80	94

Table 10. Taguchi parameters for the six criteria.

Criteria	Target Value (%)	Range (%)	Specifiction Limit for the Deviation (%)	Loss Coefficient (k)	Taguchi Loss Function
Quality	100	100~85	15	2500	$L(X) = 2500(X - T)^2$
Maintenance	100	100~70	70	400	$L(X) = 400(X - T)^2$
Warranty	100	100~90	10	10,000	$L(X) = 10,000(X - T)^2$
Technical	100	100~85	15	625	$L(X) = 625(X - T)^2$
Reputation	100	100~80	20	1111	$L(X) = 1111.11(X - T)^2$
Price	100	100~90	10	10,000	$L(X) = 10,000(X - T)^2$

Table 11. Individual and weighted loss scores for the six criteria.

	Quality		Maintenance		Warranty		Technical		Reputation		Price		Weighted Score	Normalized
Supplier	Weight	Loss	Weight	Loss	Weight	Loss	Weight	Loss	Weight	Loss	Weight	Loss		
Supplier1	0.151	25	0.062	49	0.079	100	0.241	76.56	0.039	99.99	0.428	64	64.46	0.381
Supplier2	0.151	56.25	0.062	36	0.079	36	0.241	39.06	0.039	69.44	0.428	100	68.49	0.405
Supplier3	0.151	16	0.062	31.36	0.079	16	0.241	56.25	0.039	44.44	0.428	36	36.32	0.215

Table 12. Analytic hierarchy process (AHP)-Taguchi loss function (TLF)-multi-choice goal programming (MCGP) model solution programming.

AHP-TLF-MCGP Model Solution Programming	AHP-TLF-MCGP Model Goal
Min $z =$ $(w_1(0.151(dp_1 + dn_1 + ep_1 + en_1))$ $+ (0.062(dp_2 + dn_2 + ep_2 + en_2))$ $+ (0.079(dp_3 + dn_3 + ep_3 + en_3))$ $+ (0.241(dp_4 + dn_4 + ep_4 + en_4))$ $+ (0.039(dp_5 + dn_5 + ep_5 + en_5))$ $+ (0.428(dp_6 + dn_6 + ep_6 + en_6))$ $+ ((w_2(dp_7 + dn_7 + ep_7 + en_7)))$ s.t $w_1 + w_2 = 1; w_1 = 0.8; w_2 = 0.2$ $(0.096 x_1 + 0.039 x_2 + 0.016 x_3) b_1 - dp_1 + dn_1 = y_1 b_1$ $y_1 - ep_1 + en_1 = 0.096$ $y_1 \leq 0.096$ $0.016 \leq y_1$ $(0.005x_1 + 0.014x_2 + 0.043x_3) b_2 - dp_2 + dn_2 = y_2 b_2$	Satisfy quality goal Satisfy maintenance goal Satisfy warranty goal Satisfy technical goal Satisfy reputation goal Satisfy price goal Satisfy loss function goal For quality goal, the less the better For $ y_1 - g_{1,min} $ For bound of the y_1 For maintenance goal, the less the better

Table 12. Cont.

AHP-TLF-MCGP Model Solution Programming	AHP-TLF-MCGP Model Goal
$y_2 - ep_2 + en_2 = 0.043$	For $ y_2 - g_{2,min} $
$y_2 \leq 0.043$	For bound of the y_2
$0.005 \leq y_2$	
$(0.005x_1 + 0.021x_2 + 0.053x_3) b_3 - dp_3 + dn_3 = y_3 b_3$	For warranty goal, the less the better
$y_3 - ep_3 + en_3 = 0.053$	For $ y_3 - g_{3,min} $
$y_3 \leq 0.053$	For bound of the y_3
$0.005 \leq y_3$	
$(0.014x_1 + 0.156x_2 + 0.071x_3) b_4 - dp_4 + dn_4 = y_4 b_4$	For technical goal, the less the better
$y_4 - ep_4 + en_4 = 0.156$	For $ y_4 - g_{4,min} $
$y_4 \leq 0.156$	For bound of the y_4
$0.014 \leq y_4$	
$(0.004x_1 + 0.024x_2 + 0.011x_3) b_5 - dp_5 + dn_5 = y_5 b_5$	For reputation goal, the less the better
$y_5 - ep_5 + en_5 = 0.024$	For $ y_5 - g_{5,min} $
$y_5 \leq 0.024$	For bound of the y_5
$0.004 \leq y_5$	
$(0.271x_1 + 0.111x_2 + 0.045x_3) b_6 - dp_6 + dn_6 = y_6 b_6$	For price goal, the less the better
$y_6 - ep_6 + en_6 = 0.271$	For $ y_6 - g_{6,min} $
$y_6 \leq 0.271$	For bound of the y_6
$0.045 \leq y_6$	
$(0.381x_1 + 0.405x_2 + 0.215x_3) b_7 - dp_7 + dn_7 = y_7 b_7$	For loss function goal, the less the better
$y_7 - ep_7 + en_7 = 0.215$	
$b_1 = b_2 + b_3 + b_4 + b_5 + b_6 + b_7$	To ensure the quality goal and the others, zero should be achieved.
$b_2 + b_3 + b_4 + b_5 + b_6 + b_7 = 1$	Added auxiliary constraints can force the quality goal and either of the other goals to be achieved.
$x_1 + x_2 + x_3 = 1$	Select a supplier
$x_i \geq 0, i = 1, 2, 3$	
$d_i^+, d_i^-, e_i^+, e_i^- \geq 0, i = 1, 2, \dots, 7$	

The general steps of the AHP-FLP and AHP-TLF-MCGP models are summarized in Figure 2.

4.2. Real-World Application of the Proposed Model

We conducted a case study on Taoyuan International Airport Services Co., Ltd. (TIAS) Taoyuan city, Taiwan, constituting the AGHS. In 2018, TIAS provided ground handling services for 81,789 flights, serviced over 27.2 million passengers, and handled over 1.82 million tons of cargo. TIAS has powered (vehicle quantity: 749) and nonpowered (vehicle quantity: 5584) airport ground handling equipment. The intend of this study was to enable accurate estimations based on all possible decisions and help DMs satisfy company purchasing requirements. DMs often have difficulty choosing the most suitable supplier when various alternatives are available.

To ensure that our model had real-world utility, a decision expert team was structured; it comprised of two vice presidents with responsibility for AGHS company and four mechanical supply and repairs managers employed by TIAS. Ultimately, a foundation for such decisions was provided for applying the aforementioned steps, ensuring optimal decision-based outcomes [36].

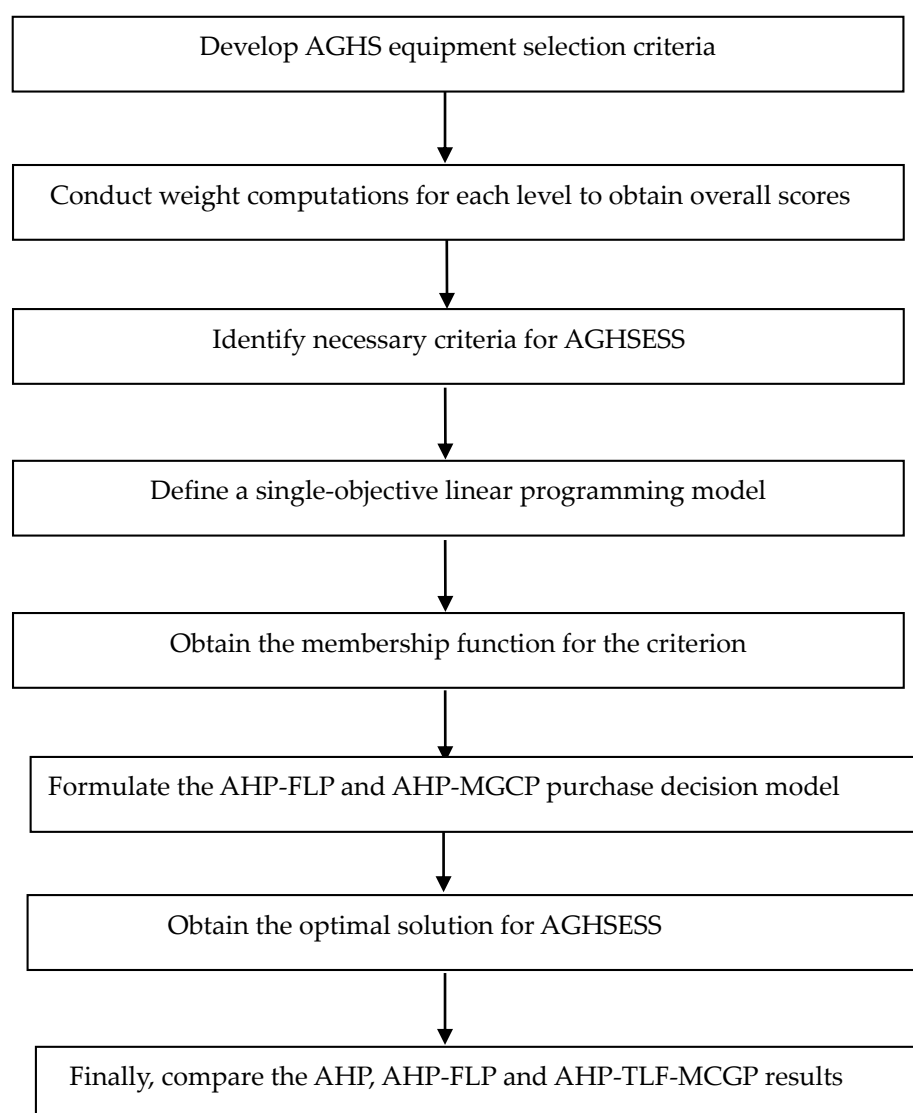


Figure 2. Steps of the proposed method.

4.3. Identification of Necessary Decision Criteria for Equipment Selection

The main decision criteria should relate to the choice of AGHS equipment suppliers, which are ultimately decided by expert team. The experience and qualification of the expert team were harnessed to decide on the vital criteria for AGHSESS. Details of the equipment supplier decision criteria are provided in Table 1 [14].

According to the aforementioned criteria, the AGHS equipment suppliers that were below enlargement or in procedure were examined, and a decision-making team chose six major supplier criteria that matched the company's needs. The six criteria are outlined as follows: Quality management (SC1), good production capacity and maintenance (SC2), product warranty (SC3), technical transfer provision (SC4), good cooperative relationship and reputation (SC5), and reasonable prices for parts (SC6). These criteria were used in our assessment and a decision hierarchy was subsequently constructed. The decision hierarchy based on the chosen AGHS equipment suppliers and their criteria is presented in Figure 3.

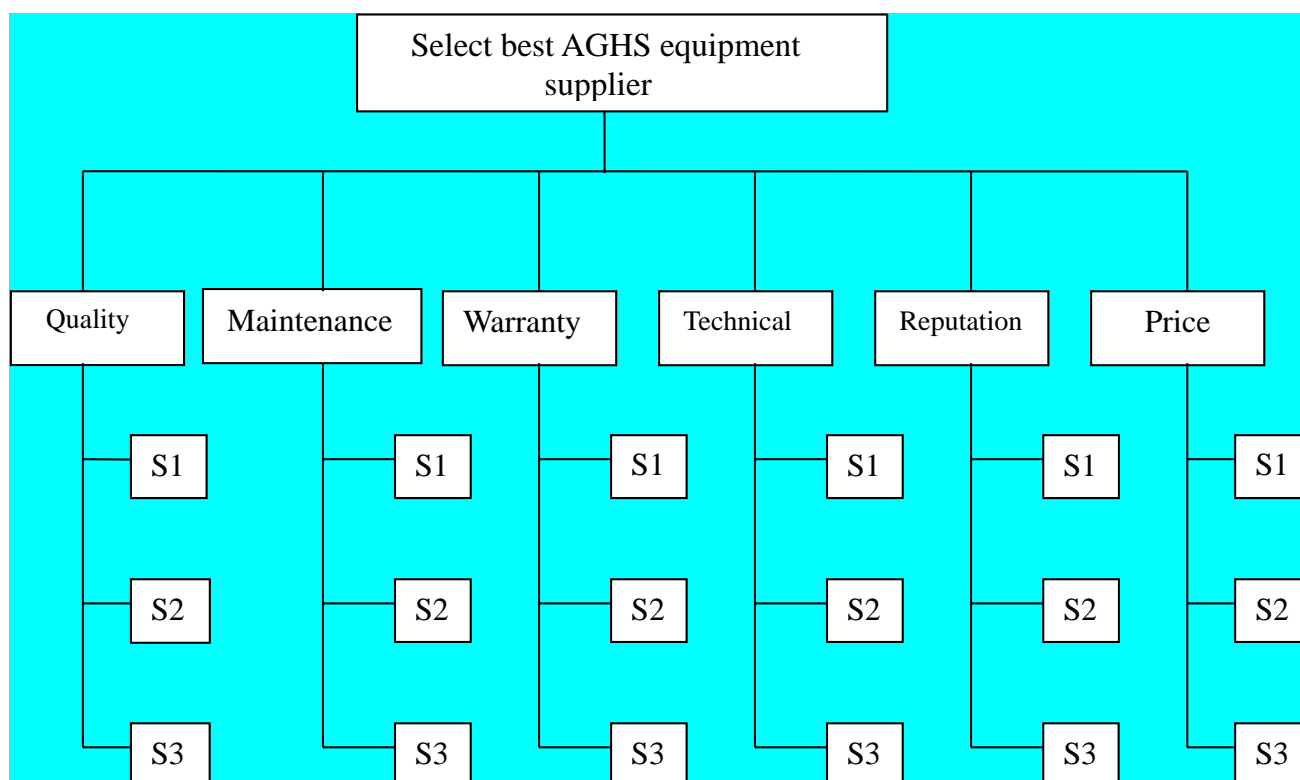


Figure 3. Decision hierarchy.

4.4. Calculation of Criteria Weights

Decision hierarchy criteria weights for use to calculate were computed using the AHP. Accordingly, the expert team developed a pairwise comparison matrix using the scale provided in Table 2. The geometric indices related to assessments were determined to establish a pair-wise comparison template, and broad agreement was reached on its content (Table 3). The results of the calculations based in Tables 4 and 5 [24].

Through the AHP, SC1 (quality management), SC4 (product warranty), and SC6 (providing technical transfer) were determined as the three vital criteria in the equipment DM process. A pairwise comparison template of the reliability coefficient of the existed revealed designate $0.084 < 0.1$. Therefore, the weights were determined to be reliable, and they were used in the following decision-making procedures [24].

4.4.1. Constructing a Linear Programming Model for Real-World Application

The supplier DM process was founded on the assessments of our decision expert team. This result was that all suppliers could be analyzed by referring to the six aforementioned criteria and pairwise comparison could be made based on the key criteria. Tables 5–7 presents the evaluation criteria for each equipment provider, which was derived with reference to the key supplier decision criteria.

Details of the linear programming model used for AGHSESS are presented in [5]. A linear membership function is used for fuzzifying (i.e., to render unclear or vague) the purpose utilities with the resource constraints indicated in the aforementioned selection problem. The dataset used to set standards for the lower (z_k^{\min}) and upper (z_k^{\max}) bounds of purpose utilities is presented in Table 8.

4.4.2. Fuzzy Multi-Objective Decision Model

The relationship between the six criteria and related weights are presented herein to maximize the presentation of the providers associated with all key AGHS decision factors. Accordingly, we can derive quality criteria to determine the utility of Z_1 .

The utility of z_1 (quality), which is shown in Figure 4, can be calculated according through Equation (8):

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

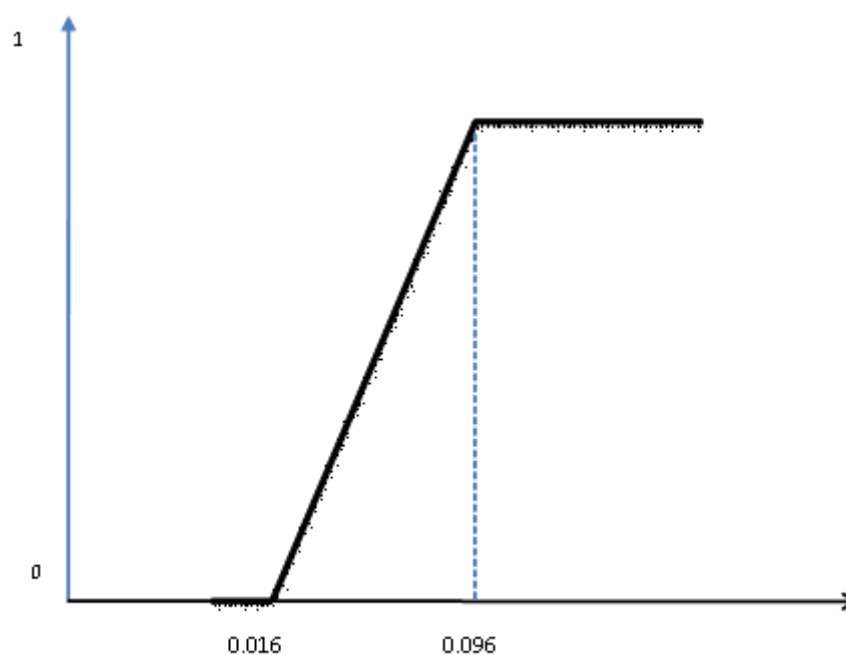


Figure 4. Membership function of quality.

On the basis of this condition, the following fuzzy linear model can be derived:
Obtain a vector X , where $X = [x_1, x_2, x_3]$ toward assure:

$$\begin{aligned} \max \tilde{z}_1 &= 0.096x_1 + 0.039x_2 + 0.016x_3 \sim z_1^0 \\ \max \tilde{z}_2 &= 0.005x_1 + 0.014x_2 + 0.043x_3 \sim z_2^0 \\ \max \tilde{z}_3 &= 0.005x_1 + 0.021x_2 + 0.053x_3 \sim z_3^0 \\ \max \tilde{z}_4 &= 0.014x_1 + 0.156x_2 + 0.071x_3 \sim z_4^0 \\ \max \tilde{z}_5 &= 0.004x_1 + 0.024x_2 + 0.011x_3 \sim z_5^0 \\ \max \tilde{z}_6 &= 0.271x_1 + 0.111x_2 + 0.045x_3 \sim z_6^0 \end{aligned}$$

subject to:

$$\begin{aligned} x_1 + x_2 + x_3 &= 1 \\ x_i &\geq 0, i = 1, 2, 3. \end{aligned}$$

4.4.3. Formulation of the AHP-FLP Purchase Decision Model

In this case, the weights (w_k) related to the k th objective are obtained pair-wise comparison of the key decision criteria determined using AHP are presented in Table 7, such as “line middling”. Tables 5–7 are an indication that the total weights are equivalent to 1 (details of the approach are provided in [14]).

After the formulation of the AHP-FLP decision model and resolution of Equations (6)–(13), the single-objective model, which relates to the aforementioned fuzzy linear purchasing decision model, can be described 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:

$$\begin{aligned}\lambda_1 &\leq \frac{0.096 - (0.096x_1 + 0.039x_2 + 0.016x_3)}{0.096 - 0.016} \\ \lambda_2 &\leq \frac{0.043 - (0.005x_1 + 0.014x_2 + 0.043x_3)}{0.043 - 0.005} \\ \lambda_3 &\leq \frac{0.053 - (0.005x_1 + 0.021x_2 + 0.053x_3)}{0.053 - 0.005} \\ \lambda_4 &\leq \frac{0.1564 - (0.014x_1 + 0.156x_2 + 0.071x_3)}{0.156 - 0.014} \\ \lambda_5 &\leq \frac{0.024 - (0.004x_1 + 0.024x_2 + 0.011x_3)}{0.024 - 0.004} \\ \lambda_6 &\leq \frac{0.271 - (0.271x_1 + 0.111x_2 + 0.045x_3)}{0.271 - 0.045} \\ \lambda_i &\geq 0, \lambda_i \leq 1, i = 1, 2, 3, 4, 5, 6.\end{aligned}$$

4.4.4. Solving the AHP-FLP Purchase Decision Problem

After the Lingo [39] was used to resolve this AGHS equipment provider problem, the best result was obtained as follows:

$x_1 = 0, x_2 = 0, x_3 = 1$, indicating that equipment provider A3 was the optimal choice according to the DMs preferences.

Objective (Z_k) and membership ($\mu_{zk}(x)$ or λ_k) functions for quality assessment can be expressed as follows:

$$\begin{aligned}z_1 &= 0.016, z_2 = 0.043, z_3 = 0.053, z_4 = 0.071, z_5 = 0.011, z_6 = 0.045 \\ \mu_{z1}(x) &= \lambda_1 = 0, \mu_{z2}(x) = \lambda_2 = 1, \mu_{z3}(x) = \lambda_3 = 1, \mu_{z4}(x) = \lambda_4 = 0.401, \\ \mu_{z5}(x) &= \lambda_5 = 0.350, \mu_{z6}(x) = \lambda_6 = 0.\end{aligned}$$

The quality assessments showed that the values for Z_3 , (product warranty), Z_4 , (technical transfer), and Z_6 , (reasonable prices for parts) were higher than those for Z_1 , (quality management), Z_2 , (production capacity and maintenance), and Z_5 , (good cooperative relationship and reputation). The success of the model depends on the DM's preferences and the related decision criteria. Equipment supplier A3 was the optimal choice in this context.

4.4.5. Comparison of AHP-TLF-FLP and AHP-TLF-MCGP Model Results

For the sake of reducing the AHP and AHP-FLP model approaches' drawbacks and reaching precise results, in this solution, corresponding to DM's preferences ($w_1 = 0.8, w_2 = 0.2$), Table 12 presents AHP-TLF-MCGP model solution programming to solve AGHSESS problem.

After, Lingo was used to resolve the aforementioned AGHSESS decision problem, and the optimal resolution derived from the AHP-TLF-MCGP model is outlined as follows: $x_1 = 0, x_2 = 0, x_3 = 1, y_1 = 0.016, y_2 = 0, y_3 = 0.005, y_4 = 0.014, y_5 = 0.004, y_6 = 0.045, y_7 = 0.215$. The finding that supplier A3 was the most appropriate one in the AHP-TLF-MCGP approach confirmed the views of the AGHSESS team.

The AHP, TLF, FLP, and MCGP approaches outperformed the AHP approach in solving the AGHSESS problem when supplier selection criteria were imposed. When AHP model was used without constraints, Supplier A1 was identified as the optimal one. This contradicts the AHP-FLP and AHP-TLF-MCGP models results in that Supplier A3 was determined to be the best option. In AGHSESS problems, the AHP-TLF-MCGP model can effectively handle vague and imprecise input data and criteria with varying relative weights. The AHP-TLF-MCGP model was implemented by integrating the AHP and TLF methods with MCGP to solve AGHSESS problems. This decision model can assist the DMs determine the suitable stock to order from each AGHS supplier provider, and it permits purchasing managers to easily select the optimal supplier in terms of criteria such as quality management, production capacity, product maintenance, product warranty, technical transfer provision, good cooperative relationship, and reputation, and reasonable prices for parts. With a few modifications, the model can also be in the habit of overcome other DM problems, such as those encountered by an overseas AGHS provider or others aviation industry firms.

5. Conclusions and Implications

5.1. Conclusions

The results obtained from the AHP and AHP-FLP decision model are compared in Table 13. The total scores for all providers are provided in this table; such scores were obtained using the aforementioned purchase decision model. As indicated, when the AHP model was used, equipment supplier A1 was recognized as the best choice when no constraints were imposed. When the AHP-FLP model was used and constraints were imposed, equipment supplier A3 was determined to be the best choice. This finding confirmed the postulations of the supplier selection team, giving credence to the argument that the AHP-FLP model would outperform the AHP model in this context.

Table 13. Comparison of the AHP, AHP-fuzzy linear programming (FLP), and AHP-TLF-MCGP model purchase decision model results.

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

Note: $0.385^* = 0.574 \times 0.151 + 0.077 \times 0.062 + 0.064 \times 0.079 + 0.057 \times 0.241 + 0.096 \times 0.039 + 0.633 \times 0.428$.

AGHSESS is a pertinent concern and affects AGHS providers in terms of staff members' daily duties and work safety. In our study, we compared AHP and AHP-FLP decision models to evaluate the selection of AGHS equipment suppliers. We used triangular fuzzy numbers to conduct linguistic assessments in order to assess the individual decisions of experts; subsequently, we derived the AHP-FLP and AHP-TLF-MCGP decision models for making group assessments. To provide a real-world example, we conduct a case study on an AGHS supplier in Taiwan. The AHP-FLP and AHP-TLF-MCGP decision model outperformed the AHP technique in terms of AGHSESS under conditions of limited selection criteria. Of the six AGHS equipment suppliers for the AGHS company considered in our case study, supplier A1 was determined to be the optimal supplier when the AHP model was used without constraints imposed. After the AHP-FLP and AHP-TLF-MCGP model was used, supplier A3 was determined to be the most suitable choice. In this case study, this model could deal with inaccurately entered information and criteria with varying relative weights. The results through the AHP-FLP and AHP-TLF-MCGP model corresponded to the real-world AGHSESS decisions of purchasing managers.

5.2. Management Implications

In this study, AHP and AHP-FLP models were compared in terms of how they helped personal deal with supplier selection problems. The integrated model can enable the aviation industry purchasing managers to observe all their options clearly under considerations of quality management, production capacity, product maintenance, product warranty, technical transfer provision, good cooperative relationship and reputation, and reasonable prices for parts. Two advantages are gained from using the AHP-TLF-MCGP model to solve AGHSESS problems: First, it permits DMs to set multiple desire levels related to supplier provider criteria, and second, it facilitates problem solving. Furthermore, the AHP-TLF-MCGP model is possibly beneficial on behalf of solving different MCDM problems, for instance those involving vague data.

5.3. Limitations

We combined the TLF and MCGP models that were integrated with the AHP model to capture the AGHSESS problem of fuzziness in human judgment and account for resource constraints. To reduce the AHP and AHP-FLP model approaches' disadvantages and reach precise outcomes, we compared them with the AHP-TLF-MCGP decision model to verify the AGHSESS problem. Formerly, if DMs use a new AHP technique and a

combination of other goal programming methodologies, there can be a dissimilar result in hesitant situations.

5.4. Future Research Directions

Individual constraints in this model are a concern when the multiattribute weighting method is used [40]. The weights chosen to be used in the AHP technique may be regarded as biased. The data envelopment analysis (DEA) technique partly entails an optimization process conducted using linear programming; therefore, it can be used to determine weights. Several authors such as Pitchipoo, [37,41] have indicated that weights may be determined using DEA. These weights can be derived independently and thus involve less bias compared with those derived through other techniques. Accordingly, future research can be conducted on the use of this technique for deriving weights in our proposed model.

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