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Chang-Shu Tu
Department of Business Administration, Chien Hsin University of Science and Technology, Taoyuan County, Taiwan, R.O.C, long.tree@msa.hinet.net

Chan-Shal Lee
Department of Shipping and Transportation Management, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.

Shing-Chih Yang
Department of Shipping and Transportation Management, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.

Hsuan-Shih Lee
Department of Shipping and Transportation Management, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.

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A COMPARISON OF MODELS USED FOR AIRCRAFT TRACTOR SUPPLIER SELECTION FROM A FINANCIAL PERSPECTIVE

Chang-Shu Tu[1], Chan-Shal Lee[2], Shing-Chih Yang[2], and Hsuan-Shih Lee[2]

Key words: supplier selection, Delphi method, analytic hierarchy process, involvement cost-factor measure, multi-choice goal programming.

ABSTRACT

Aircraft tractor supplier selection (ATSS) is critical for equipment procurement management in airport ground handling service (AGHS) companies because it guarantees the work safety of airport ramps. Although AGHS ATSS plays a crucial role in the safety of ground handling ramp operations, few studies have analyzed the ATSS of AGHS companies. This paper describes a new approach to compare the Delphi method, analytic hierarchy process, involvement cost-factor measures, and multi-choice goal programming by considering both financial and nonfinancial factors for ATSS from a financial perspective. In particular, we introduce a real case to demonstrate the practicability of the proposed approach.

I. INTRODUCTION

The main objective of airport ground handling service (AGHS) companies is to ensure the work safety of moving aircraft in airside ramp operations, which includes avoiding aircraft damage, reducing the handling time of ground services, ensuring high handling reliability, and avoiding delays (Ashford et al., 1997). An Airport Council International (ACI) survey of 193 airports showed that delays were caused by malfunctions of baggage handling, loading processes and handling equipment malfunctions. The goal of the ACI's survey was to prevent future apron incidents and accidents. A total of 3,233 apron incidents and accidents were reported during the handling of 15,119,020 aircraft movements, resulting in a rate of 0.214 incidents/accidents per 1,000 movements or one incident per 4,676 aircraft movements. These problems are often due to malfunctions of passenger handling or aircraft servicing equipment (e.g., aircraft tractors) (Kazda and Caves, 2007). Although AGHS aircraft tractor supplier selection (ATSS) plays a crucial role in the safety of ground handling ramp operations, research investigating related problems is lacking, with few studies having analyzed the AGHS ATSS problem. For example, Bard and Sousk (1990) adopted the analytic hierarchy process (AHP) with 12 attributes to evaluate robot-assisted cargo handler selection. However, they did not focus on optimizing aircraft tractor supplier characteristics or overcoming problems in ramp operations work environments. Instead, they focused on airport ground service handlers, who must rely on the safety of technologically advanced AGHS equipment, such as aircraft tractors, for their work safety. Thus, AGHS companies tend to demonstrate concern regarding the performance and quality of their aircraft tractors. The objective of this study was to develop a new approach to ATSS problems by combining the cost components of AGHS equipment supplier characteristics with other evaluation criteria. An involvement of cost-factor measures (ICFM) model integrating the Delphi method and AHP (DHP) is proposed to incorporate qualitative and quantitative measures to address ATSS problems. The weighted DHP and ICFM models comprise six decision criteria that were determined from interviews and a survey by a team of ATSS experts. The decision criteria are: quality management, production capacity and maintenance, product warranties, technical transfer capabilities, reputations, and prices. In the present study, these DHP results were compared with those obtained from the ICFM model to determine which method would be more helpful for AGHS company managers in selecting optimal aircraft tractor suppliers. Finally, we employed multi-choice goal programming (MCGP) to solve constraint problems defined by buyers' budgets and suppliers' capacities. The objective of this study was to present a new approach to resolving ATSS problems from a financial perspective. In summary, our study's contribution demonstrates the effective uses of ATSS problem-solving approaches, which consider aircraft tractor total cost, supplier capacity, net present value (NPV)-based cash outflow, NPV-based cash inflow, NPV-based return on investment (ROI), and suppliers' capac-

Paper submitted 23/08/12; revised 08/15/15; accepted 02/17/16. Author for correspondence: Chang-Shu Tu (e-mail: long.tree@msa.hinet.net).
[1] *Department of Business Administration, Chien Hsin University of Science and Technology, Taoyuan County, Taiwan, R.O.C.*
[2] *Department of Shipping and Transportation Management, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.*

ity levels. Specifically, we provide a real AGHS company case example and apply the proposed approach to resolve the ATSS problem in Taiwan.

The remainder of the paper is structured as follows: Section II outlines the proposed methods and Section III details the proposed comparison model for ATSS problems. Section IV compares the DHP selection process and ICFM model results by applying the proposed model to a real example. Subsequently, a sensitivity analysis using the proposed model is described to demonstrate the confidence level of the decision. Finally, we use the MCGP approach to solve the constraint problems of buyers' budgets and suppliers' capacities. Finally, Section V presents the findings and conclusions.

II. LITERATURE REVIEW

1. Literature Review of General Supplier Selection

General supplier selection is discussed extensively in the literature. For example, Monczka and Callahan (1992) suggested using factor analysis to assess supplier value. Vonderembse and Tracey (1999) investigated 268 purchasing managers to determine the individual supplier selection criteria that address in-product development activities and continuous improvement efforts. The researchers found that suppliers learn about their customer's requirements, culture, and decision-making patterns to facilitate adjusting and allocating resources. Since the 1960s, researchers in this field have focused on supplier selection criteria and supplier performance. However, no previous study has addressed ATSS from a financial perspective. The relationships among goals, activities and performance measures have been established using an AHP approach to derive an ICFM model (Bhattacharya and Mukherjee, 2005). This study investigated AGHS equipment characteristics by applying the DHP technique. Specifically, the investigation proceeded empirically by conducting interviews and a survey with a team of AGHS experts, and ICFM model results were compared to draw conclusions regarding the practicality, acceptability, and suitability of the DHP method (Bard and Sousk, 1990). The present work demonstrates the practicability of DHP approaches for generating ICFM models that involve considering capital investments. The remaining sections of this manuscript discuss the DHP and ICFM approaches and then present the proposed comparison model and its applications.

2. Literature Review of the Proposed Methodology

Although several techniques and models have been effectively used to evaluate supplier performance, few studies have incorporated financial measurements into the ATSS evaluation process. Bhattacharya et al. (2005) proposed an ICFM model to evaluate the economics of industrial robot selection problems. Researchers developed an ICFM model that is highly suitable for selecting a robot or robotic system from a financial perspective. The ICFM model involved considering several variables: direct and indirect costs, strategic benefits of the proposed investment, technical requirements, and customer requirements. Anand et al. (2008) also proposed an ICFM model for robot system selection. However, the AHP method does not consider tangible factors such as cost (Saaty, 1980, 1986, 1990). Thus, cardinal ranking of the alternatives should be included in the AHP method to improve the model's robustness and efficiency. The methodology proposed herein may facilitate quantifying intangible factors and ascertaining optimal solutions among alternatives that depend on cost factors. In this paper, a robust ICFM model that incorporates DHP is proposed to incorporate qualitative and quantitative measures to address ATSS problems. To aid AGHS company equipment-procurement managers in solving the problems arising from buyers' budget and suppliers' capacity constraints, we adopted MCGP to address the ATSS problem. The available financial information (e.g., aircraft tractor acquisition cost, initial spare parts cost, maintenance cost, technical training cost, installation cost, shipment cost, and service cost) is incomplete and uncertain, rendering it nearly impossible for decision makers (DMs) to construct a reliable mathematical model to illustrate their preferences (Chang, 2008). Difficult trade-offs must be made to allocate resources within the constraints of buyers' budgets and suppliers' capacities. The advantage of MCGP is that it addresses conflicts of resources and the incompleteness and uncertainty of the available information. DMs must consider not only a solitary aspiration level in the local region, but also multiple aspiration levels under the given constraints to obtain a globally optimal solution. MCGP enables DMs to set multi-choice aspiration levels (MCALs) for each goal (i.e., one goal mapping multiple aspiration levels) to avoid the underestimation of decision making (Ustun, 2012). To overcome this problem, many approaches have been developed, and many methodologies have been applied. The goal programming (GP) method, which is rooted in mathematical programming, combines the logic of optimization with the DM's desire to satisfy several goals (Patia et al., 2008); the MCGP method can be adopted to address the complexities of analytical ATSS cases and to reliably generate the best possible solution.

III. METHODS

This section introduces the Delphi method, AHP method, ICFM model and MCGP to solve ATSS problems.

1. Delphi Method

The Delphi method was developed by the RAND Corporation in the 1960s and is generally used in forecasting. Group decision-making problems can be easily formulated using the Expert Choice software package (Forman et al., 1983; Dyer and Forman 1992; Byun, 2001). The Delphi method is widely accepted as an effective tool for various applications such as strategic planning, knowledge capturing, objectives setting, defining attributes and factors for market research, large-scale project planning, new product development, and systems design.

The Delphi method was developed by Helmer (1963) and Helmer (1966) as a systematic procedure for eliciting expert

Table 1. Scale used for pairwise comparison.

Value	Definition	Explanation
1	Equal preference	Both factors contribute equally to the objective or criterion
3	Weak preference of one over	Experience and judgment the other slightly favor one factor over the other
5	Essential or strong	Experience and judgment preference strongly favor one factor over another
7	Very strong or demonstrated Preference	A factor is favored very strongly over another; its dominance is demonstrated in practice
9	Absolute preference	The evidence favoring one factor over another is unquestionable
2, 4, 6, 8	Intermediate values	Used when a compromise is needed

opinions. According to Dalkey and Helmer (1963) the Delphi method is characterized by the following three features: (i) anonymity, (ii) controlled feedback, and, (iii) statistical group response. Anonymity is achieved using questionnaires and other formal communication channels, such as online computer communication, and provides a tool for reducing the effects of dominant individuals. Controlled feedback reduces noise by conducting exercises in sequence and communicating the results of the previous round to the participants between exercises.

The statistical group response is a device that ensures the opinion of every group member to be represented in the final response. Multiple variations of the three basic DHP features can be employed (Khorramshahgol and Gousty, 1988). Through the Delphi inquiry, the views of the DMs and people involved in solving ATSS problems can be collected and used to generate new concepts, suggestions, and alternatives.

2. The AHP Method

The AHP method is a decision-supported procedure that was developed by Saaty, (1980) to make complex, unstructured and multiple-criteria decisions. This method is analysis is extended one step further, a consistency index (*CI*) can be derived to measures this discrepancy (Bard, based on model structure, comparative judgment of alternative criteria, and priority synthesis. Previous studies have adopted AHP methods extensively to solve complex decision-making problems (Saaty, 1980, 1988, 1990). In the AHP method, multiple pairwise comparisons are made on the basis of a nine-level standardized scale (Table 1). The relevant index should be lower than 0.10 for AHP results to be consistent. If the final consistency ratio exceeds 0.10, then the DM should reevaluate the assessments and comparisons. Saaty (1980) stated that, in many

Table 3. Primary criteria matrix (for Expert Respondent No. 1).

	Quality	Maintenance	Product warranty	Technical transfer	Reputation	Price
Quality	1	3	7	5	8	8
Maintenance	1/3	1	1/2	1/4	4	3
Product warranty	1/7	2	1	1/3	3	2
Technical transfer	1/5	2	1/3	1	4	3
Reputation	1/8	1/2	1/3	1/4	1	1/2
Price	1/8	1/3	1/2	1/3	2	1

practical cases, the pairwise judgments of decision-makers contain a level of uncertainty. When n factors are being compared, n (n-1)/2 questions are necessary to complete the matrix. The second half of the comparison matrix, which is usually omitted, contains the reciprocals of those judgments lying above the diagonal (Tung and Tang, 1998; Sevkli et al., 2008) and is expressed as $a_{ji} = 1/a_{ij.}$ The entries in the matrix at the center of Table 3 are the responses to the 15 pairwise ($n = 6$) questions. These responses were based on the nine-level scale indicated in Table 1. For example, when comparing performance with maintenance (i.e., element a_{12} of the matrix), the first response was judged to dominate the second response strongly. Notably, if the obtained value of this matrix had been 1/3 instead of 3, then the opposite outcome would have been true. After the DM supplies all the data for the matrix, the following equation is solved to obtain the rankings (w):

$$Aw = \lambda_{\max} w \tag{1}$$

where w is the n-dimensional eigenvector associated with the largest eigenvalue $\lambda_{\max}$ of the comparison matrix A. The n components of w are then scaled to 1. The consistency of the responses and transitivity of the preferences are verified by ascertaining whether the following equation holds:

$$a_{ij} = a_{ik}\ a_{kj},\ \text{for all } i, j, k. \tag{2}$$

In practice, DMs estimate only the true elements of A by assigning the values from Table 1; therefore, the perfectly consistent case represented by Eq. (2) is unlikely to occur. As an approximation, the elements of A can be thought to satisfy the following relation: $a_{ij} = w_i / w_i + \varepsilon_{ij}$, where ε_{ij} is the error of judgment relative to the DM's inconsistency when comparing factor i to factor j. When the 1986; Harker and Vargas, 1987). A value of 0.05, for example, can be interpreted as indicating that there is a 5% chance that the matrix was completed randomly. Experience suggests that the value of *CI* should be less than 0.10 to assume full confidence in the results. This assertion implies a certain amount of subjectivity, very similar to the uncertainty associated with interpreting the coefficient of determination in regression analysis. As the number of factors in the model increases, the results become less sensitive to the values in any one matrix (for steps on addressing unreasonably high values, refer to Saaty, 1980).

3. The ICFM Model

This section describes an ICFM model based on the Brown and Gibson model (Brown and Gibson, 1972) and discusses its advantages and limitations. The Brown and Gibson model has been widely applied to numerous problems, such as advanced manufacturing technologies (Meredith and Suresh, 1986), the choice of technology (Punniyamoorthy and Ragavan, 2003), and the evaluation of services (Parameshwaran and Srinivasan, 2008). The advantages of the ICFM model are discussed as follows (Meredith and Suresh, 1986; Meredith and Hill, 1987; Punniyamoorthy and Ragavan, 2003; Parameshwaran, and Srinivasan, 2008).

4. The Advantages of the ICFM Model

The ICFM model is flexible because it combines objective economic factors with subjective strategic factors and leads to explicit and objective numerical conclusions.

(i) It is simple and comprehensible; it can quantify the subjective factors, thus ensuring objectivity in the final solution.
(ii) It is not a strict mathematical model; however, it offers significant guidance for DMs.

5. Limitations of the ICFM Model

The ICFM approach does have several shortcomings, which are discussed in this section (Hauser and Tadikamalla, 1996; Pette and Componation, 2002; Punniyamoorthy and Ragavan, 2003; Sun and Leu, 2007). If the model is inappropriately developed, then the flexibility and freedom of choice that it provides can lead to spurious measurements and conclusions. A degree of subjectivity exists in the choices made and the judgment of critical and subjective criteria. If the model contains a high number of criteria or if there are many alternative solutions, the process becomes complex and time-consuming. Although the basic reasons for ATSS include enhanced productivity, quality, and worker safety, the ultimate justification for selection is based on financial considerations. Thus, the proposed DHP and ICFM comparison model must be robust regarding financial issues (Bhattacharya and Mukherjee, 2005). ATSS problem solving should involve considering cost factors, which can be quantified using a novel technique to account for the cost components of selection procedures. Conventional financial approaches, such as break-even, sensitivity analyses, ROI, and payback period analyses, are inappropriate for ATSS. Instead, such considerations as direct and indirect costs, the strategic benefits of the proposed investment, as well as technical and customer requirements should be used to optimize selection. Bhattacharya and Mukherjee (2005) proposed an ICFM model that combined cost-factor components with weightings derived from DHP approaches. The governing equation of the stated model is expressed as follows:

$$SI_i = \left[(\alpha SFM_i + (1-\alpha) OFM_i \right] \tag{3}$$

where

$$OFM_i = \frac{1}{\left[OFM_i \sum_{i=1}^{n} OFC^{-1} \right]} \tag{4}$$

where *OFM* is the objective factor measure, *OFC* is the objective factor cost, *SFM* is the subjective factor measure, *SI* is the selection index, α is the objective factor decision weight, and n is the number of alternative aircraft tractor suppliers (n = 3 in the present case). The *SFM* values (i.e., the global priorities for each candidate aircraft-tractor supplier) were determined using candidates' DHP-weighted values for each factor. The product was then summed for each alternative.

The *SFM* values are ordinal measures of the customer requirements, which were obtained using the DHP method. The *OFC* values are the total costs for each candidate aircraft-tractor supplier. The *OFM* values were calculated using Eq. (4) to derive a non-dimensional measurement of cost components for each candidate aircraft-tractor supplier. This design facilitated combining the cost components (i.e., cardinal measures) with the *SFM* values (i.e., ordinal measures) in Eq. (3).

6. Multi-Choice Goal Programming

The MCGP approach includes many modified GP methods generated by previous scholars. To improve the utility of the GP techniques, Chang (2008) developed a new model for solving the multi-objectives decision-making (MODM) problems with an MCAL. The researcher's proposal to solve the MODM problem with MCAL differed considerably from fuzzy goal programming (FGP), because his model incorporated membership functions to address 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 more aspirations achieved, the more favorable the outcome). MCAL can be used to find the most suitable resources for achieving higher aspiration levels at the initial stage of the resolution process. A typical MCGP problem is expressed as follows:

In real decision-making problems, goals are often interrelated. The following addresses this problem in the MCGP equations:

$$\text{Minimize } \sum_{i=1}^{n} \left[(d_i^+ + d_i^-) + (e_i^+ + e_i^-) \right] \tag{5}$$

Subject to

$$f_i(X) b_i - d_i^+ + d_i^- = b_i y_i \quad i = 1, 2, \ldots, n, \tag{6}$$

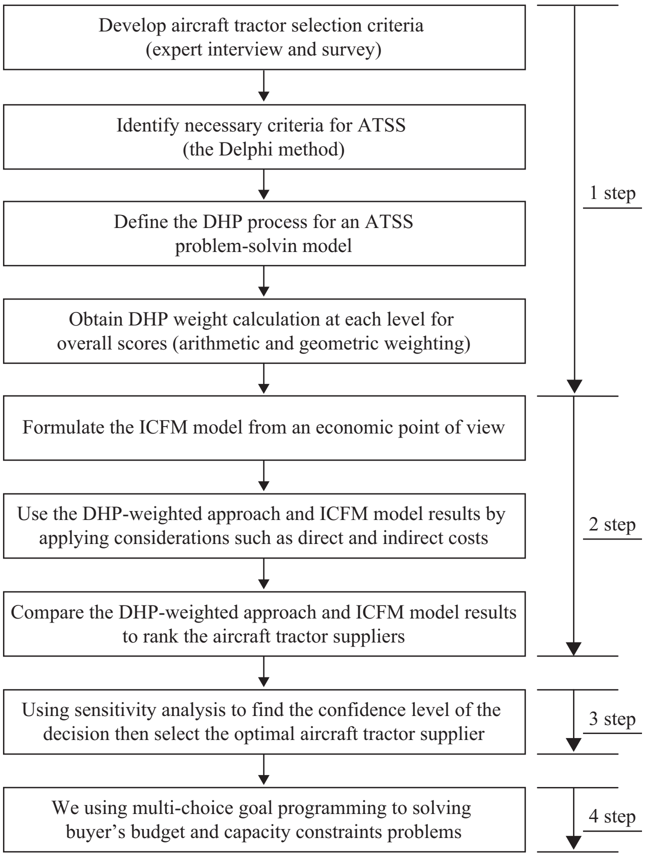

Fig. 1. Overview schematic of the proposed model.

$$y_i - e_i^+ + e_i^- = g_{i,\min} \quad i = 1, 2, \ldots, n, \tag{7}$$

$$g_{i,\min} \le y_i \le g_{i,\max} \quad i = 1, 2, \ldots, n, \tag{8}$$

$$d_i^+, d_i^-, e_i^+, e_i^- \ge 0, \; i = 1, 2, \ldots, n. \tag{9}$$

$X \in F$ where F is a feasible set and X is unrestricted in sign. (Refer to the case regarding the managerial implications of constraints in Chang, 2008).

7. Construction of the Supplier Selection Model

The model for solving the ATSS problem under the ICFM approach consists of the following three basic stages: identifying the supplier criteria to be used in the model, conducting DHP computations, and making optimal choices by adopting the ICFM approach to select the optimal aircraft tractor suppliers. In the first stage, the ATSS criteria are selected and the decision is formed. The DHP model is structured such that the objective is defined in Level 1, the evaluation criteria are listed in Level 2, and the ATSS alternatives are identified in Level 3. In the final step of the first stage, the decision hierarchy is approved by the ATSS decision-making team. After approval of the decision hierarchy, the Level 2 criteria of the ATSS are assigned weights by using DHP. Pairwise comparison matrices are formed at this stage to determine the criteria weights. Experts from the ATSS team make individual evaluations by using the scale provided in Table 1 to determine the elements of the pairwise comparison matrices. In the second stage, DHP is used to calculate the criteria weights. Criteria weights and alternative scores (termed local priorities) are considered decision elements. In the third stage, sensitivity analysis is performed to assess the proposed model in the decision process and to obtain the confidence level of the decision. Overall, the formulation of this proposed model can be expressed using the following steps:

Step 1: Identify the necessary criteria for ATSS problem solving through expert interviews and surveys.

Step 2: Determine the ATSS problem criteria and develop the hierarchical structure for optimizing ATSS, as indicated in Fig. 1.

Step 3: Have the ATSS expert team to calculate the weights for each level to obtain the overall score for each aircraft tractor supplier regarding all the criteria and to the pairwise comparisons.

Step 4: Develop an ATSS model based on the identification of the necessary criteria for ATSS solving.

Step 5: Identify the optimal aircraft tractor supplier using the DHP evaluation process.

Step 6: First, use the combined DHP approach with weighted arithmetic and geometric means to analyze the interviews with the ATSS expert team to optimize the ATSS supplier selection. Second, repeat the DHP process to formulate the ICFM model.

Step 7: Determine the ICFM model solutions for ATSS from an economic perspective (i.e., by considering the direct and indirect costs).

Step 8: Compare the DHP and ICFM model results by using Eqs. (3) and (4). (i.e., rank the aircraft tractor suppliers).

Step 9: Third, perform the sensitivity analysis on the proposed model (weighted DHP and ICFM) to determine the optimal choice. This analysis will provide all the values of α at which the weighted DHP and ICFM outputs overlap in the decision process and provide the confidence level.

Step 10: Finally, select the optimal aircraft tractor supplier. The general steps involved in comparing the DHP approaches and ICFM model are summarized in Fig. 1.

Step 11: Use the MCGP approach (Eqs. (6) and (9)) to resolve the buyers' budget constraints and suppliers' capacity constraints (for the MCGP approach, refer to the attached Appendix I).

IV. CASE EXAMPLE

1. Application of the ATSS Model to an AGHS Company

Taoyuan International Airport Services Co., Ltd (TIAS) is a

Table 2. Aircraft tractor supplier decision criteria.

Criteria	Definition
(SC_1) Quality management	
(SC_{11}) Conformance quality	Quality assurance system (ISO/TS16949/QS-9000/ISO14001) policy that is communicated, understood and maintained through the organization by performing periodic internal quality audits (Barbarosoğlu and Yazgaç, 1997; Chin et al., 1999; Sarkis and Talluri, 2002; Çebi and Bayraktar, 2003; Perçin, 2006).
(SC_{12}) Part/product definition and sorting	The availability of a non-defective parts and product definitions, as well as sorting mechanisms for defective parts and products (Barbarosoğlu and Yazgaç, 1997).
(SC_{13}) Rework	The application of reworking procedures (Barbarosoğlu and Yazgaç, 1997).
(SC_{14}) Application of advanced quality	The application of advanced quality techniques (i.e., quality function deploymenttechniques (QFD), failure mode effects analysis (FMEA), and value analysis (VA), Taguchi) in production (Barbarosoğlu and Yazgaç, 1997).
(SC_2) Production capacity and maintenance	
(SC_{21}) Manufacturing capabilities	Manufacturing capabilities including good use of statistical process control (SPCs), lean manufacturing and a so-called“kanban”system (Perçin, 2006).
(SC_{22}) Product innovation capabilities	Supplier innovation capabilities including the hardware, software (CAD/CAE/CAM), knowledge, personnel and experience (Perçin, 2006).
(SC_{23}) Maintenance services	Repair and maintenance services that support customer satisfaction (Saaty, 1980; Saaty, 1986).
(SC_3) Product warranty	
(SC_{31}) Final inspection and reliability tests	Reliable and strict inspection of the finished products in terms of functionality, performance, measurement and physical appearance; supplier ability to conduct technical experiments on finished products regarding life, durability, performance, measurements and safety (Bardand Sousk, 1990).
(SC_{32}) Measuring and testing equipment	Sufficiency technological compatibility of the measuring and testing equipment of the supplier (Barbarosoğlu and Yazgaç, 1997).
(SC_{33})Warranty support	Suppliers-tracked warranties, including an evaluation process customer satisfaction (Byun, 2001; Perçin, 2006).
(SC_{34})Response to quality problems	The ability of the aircraft tractor supplier to solve quality problems detected during production (Barbarosoğlu and Yazgaç, 1997).
(SC_4) Provision of technical transfer	
(SC_{41}) Technical information sharing	Customer demand for the efficient flow of technical information and products.
(SC_{42}) Technological compatibility	Technological compatibility of services, the materials and parts that are provided to the buying company (Barbarosoğlu and Yazgaç, 1997; Sarkis and Talluri, 2002; Çebi and Bayraktar, 2003).
(SC_{43}) Continuous improvement programs	Continuous improvement programs (e.g., Kaizen, Six Sigma) offered by the supplier for plant improvement activities (Perçin, 2006).
(SC_5) Good cooperative relationships and reputation	
(SC_{51}) Good cooperative relationships	A strong and successful buyer/supplier relationship with mutual trust and an understanding of modern techniques (Perçin, 2006).
(SC_{52}) Reputation and position	Adequate management resources, experience and capabilities in the industry on behalf of the supplier (Perçin, 2006).
(SC_{53}) Performance history	Adequate industry experience and a basic understanding of modern techniques on behalf of the supplier (Perçin, 2006).
(SC_{54}) Financial strength	Financially sound supplier (Sarkis and Talluri, 2002; Çebi and Bayraktar, 2003).
(SC_6) Reasonable price	
(SC_{61}) Compliance with cost analysis system	Supplier price increase requests in accordance with the cost system that was agreed upon by the supplier and customer (Barbarosoğlu and Yazgaç, 1997).
(SC_{62}) Cost reduction activities	Price reflection of the actual cost reduction achieved by the supplier as a result of corrective actions and technological investments (Barbarosoğlu and Yazgaç, 1997).
(SC_{63}) Reasonable parts price	Reasonable parts pricing provided by supplier (Sarkis and Talluri, 2002).

joint-venture service company owned by the China Airlines (49% ownership), the Ministry of Transportation and Communications (45% ownership), and the United Parcel Service (6% ownership). The Taoyuan Airport Terminal opened on February 26, 1979. The TIAS AGHS company smoothly integrated the officers and equipment of all Taoyuan AGHS companies, including Cathay Pacific, Northwest and TransAsia Airways ground handling companies. The TIAS AGHS company was the first ground handler in Taiwan to acquire ISO 9001 accreditation, which is an internationally recognized quality management system on maintaining high-quality service standards. As a member of the International Air Transport Association Ground Handling Council, the TIAS AGHS company maintains pace with developments in the international ground handling industry and is committed to provide top quality AGHSs. In 2008, TIAS serviced 50,267 flights, 14,025,531 passengers, and 1,441,746 ton of cargo. The TIAS AGHS company has both powered ground handling equipment (728 vehicles) and non-powered ground handling equipment (3,658 vehicles). TIAS AGHS offers various handling services for airline and air cargo businesses, and its AHGS market share is 70% at Taoyuan Airport. Our research objectives included evaluating possible ATSS solutions and assisting DMs within the TIAS AGHS company to meet their purchasing requirements. In general, ATSS is difficult because of the complex company characteristics that must be considered (e.g., quality, technical transfer, reputation and price). To meet the objectives, an ATSS expert team was formed within TIAS with one president from the AGHS department and four managers from the senior technical supply, finance, research and development (R & D) and maintenance departments. Thus, the criteria incorporated into the model were determined through interviewing and surveying the ATSS expert team, as well as by surveying all Taoyuan airport service companies' high-level supervisors, airline companies' managers, and maintenance-technical department employees. The ATSS expert team (i.e., five experts) had an average of 30 years of experience in AGHS equipment systems design, R & D program management, and government procurement practices. Pairwise comparison matrices were employed to calculate the criteria weights, which were also identified through surveys and interviews with the ATSS expert team. Application of the model preceded following the steps outlined in the previous section and is explained with the results in the following section.

2. Identification of the Decision Criteria

The decision criteria considered for the ATSS were determined by the ATSS expert team on the basis of their past experience and professional backgrounds. Explanations of the important criteria and their definitions are provided in Table 2 (Perçin, 2006). Although considerable benefits had already been realized through implementing supplier assessment forms, company management wanted to determine whether they should implement guidelines for selecting aircraft tractor suppliers. Thus, a decision-making team was formed to determine the major criteria for inclusion in the supplier selection process. After the surveys and interviews, the ATSS expert team identified six critical measures (i.e., quality, maintenance, warranty, technical transfer, reputation, and price) for selecting the optimal aircraft tractor supplier. With the assistance of the ATSS decision-making team, 21 sub-criteria were identified, followed by the introduction of AHP methodology to the decision-making team. After the AHP methodology was defined, pairwise comparisons were performed for all combinations of the criteria, sub-criteria, and alternatives. Table 2 provides the sub-criteria in various higher-level clusters (Chin et al., 1999; Muralidharan et al., 2002; Perçin, 2006). After determining the critical criteria, suppliers of aircraft tractor that were under development or in use were examined, and the ATSS expert team chose the the following six critical ATSS criteria suitable for the needs of the AGHS company: quality management (SC_1), production capacity and maintenance (SC_2), product warranty (SC_3), availability of technical transfer (SC_4), a strong cooperative relationship and reputation (SC_5), and reasonable prices (SC_6). These six criteria were used in the evaluation, and a decision hierarchy was established accordingly. Fig. 1 provides an overview of the proposed model, and Table 2 contains major criteria and sub-criteria for Level 2. Fig. 2 displays the ATSS problem-solving decision hierarchy that was constructed using the selected criteria and alternatives.

3. Calculation of the Criteria Weights

After the decision hierarchy was developed, criteria weights were computed using the AHP method. The experts on the ATSS team developed an individual pairwise comparison matrix from the scale provided in Table 1.

Table 4 lists the priority weights given by Expert 1 for the major criteria: 0.485 for quality, 0.119 for maintenance, 0.160 for product warranty, 0.137 for technical transfer, 0.043 for reputation, and 0.056 for pricing. Notably, the consistency index (0.098) was high (the consistency index value should be less than 0.10) but remained within an acceptable range. The next step in the analysis involved developing of priorities for the factors in Level 3 relative to those in Level 2. We compared three alternatives to the major criteria. The results in Table 4 indicate that the appropriate data had been elicited and that calculations had been performed for each of the four comparison matrices. The first six data columns show the local priorities that were derived from the inputs supplied by the DM. Each column sums to 1. The global priorities were calculated by multiplying these values by the higher-level local priorities in Table 4 (and repeated at the top of Table 5 for convenience) and then summing these values. The values in the last column of Table 5 represent the final priorities of Expert 1 for solving the problem because there were no more levels to evaluate. Thus, the third alternative (i.e., Supplier 3) was preferred because of their observed decision-making capabilities. Other schemes for determining the attribute weights have also been proposed (e.g., Bard and Sousk, 1990).

Table 4. Priority vectors for the major criteria (Expert Respondent No. 1).

Criteria	Priority Weight	Outpu Parameters	CR = CI / RI
1) Quality	0.485	6.605	
2) Maintenance	0.119		
3) Product warranty	0.160	CI = 0.121	0.098
4) Technical transfer	0.137		
5) Reputation	0.043	RI = 1.24	
6) Price	0.056		

Table 5. Local and global priorities. (Expert Respondent No. 1).

Alternatives	Quality (0.485)	Maintenance (0.119)	Product warranty (0.160)	Technical transfer (0.137)	Reputation (0.043)	Price (0.056)	Global priorities
Supplier 1	0.216	0.681	0.082	0.124	0.184	0.247	0.238
Supplier 2	0.262	0.252	0.305	0.312	0.227	0.386	0.280
Supplier 3	0.522	0.067	0.613	0.564	0.589	0.367	0.482

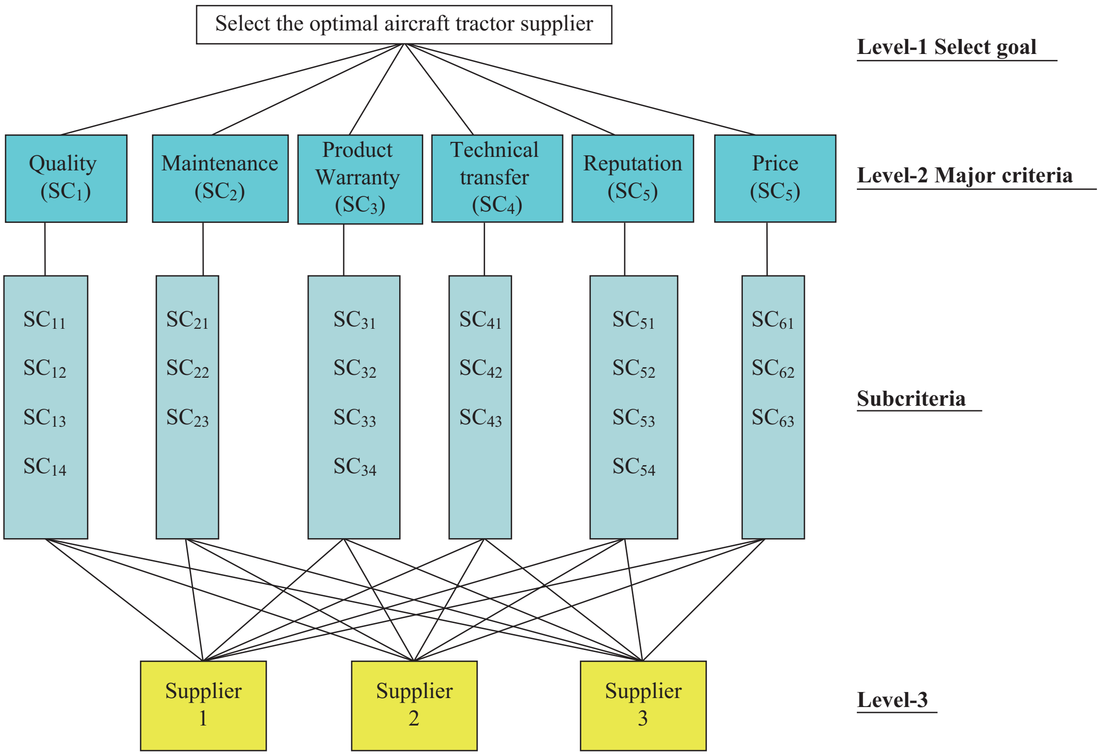

Fig. 2. ATSS problem-solving hierarchy for decision-making.

4. Data Collection and DHP Analysis

The ATSS expert team was introduced to the AHP methodology at the first meeting, and they examined the objective hierarchy that had been previously developed by the analyst. Eventually, consensus was achieved on the attribute definitions, and each member assigned values to the individual matrix elements. Following a discussion, the participants were requested to revise their entries to more accurately reflect their new understanding of the involved considerations. This phase of the study took approximately 8 hours and was conducted in two sessions over a 6-day period. As with the Delphi method procedure (Dalkey and Helmer, 1963), the challenge was to approach consensus without coercing any of the team members. In our case study of the TIAS AGHS company, sufficient agreement was obtained to permit the averaging of

Table 6. Comparison of responses using the DHP approach.

		Quality		Maintenance		Product Warranty		Technical Transfer		Reputation		Price		Global results	
Respondent	Alternative	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank
(No. 1)		(0.485)		(0.119)		(0.160)		(0.137)		(0.043)		(0.056)			
	Supplier 1	0.216	3	0.681	1	0.082	3	0.124	3	0.184	3	0.247	3	0.238	3
	Supplier 2	0.262	2	0.252	2	0.305	2	0.312	2	0.227	2	0.386	1	0.280	2
	Supplier 3	0.522	1	0.067	3	0.613	1	0.564	1	0.589	1	0.367	2	0.482	1
(No. 2)		(0.503)		(0.118)		(0.155)		(0.115)		(0.052)		(0.057)			
	Supplier 1	0.101	3	0.214	3	0.467	1	0.142	3	0.665	1	0.358	2	0.220	3
	Supplier 2	0.190	2	0.262	2	0.375	2	0.167	2	0.299	2	0.543	1	0.250	2
	Supplier 3	0.709	1	0.524	1	0.158	3	0.691	1	0.036	3	0.099	3	0.530	1
(No. 3)		(0.536)		(0.091)		(0.146)		(0.127)		(0.042)		(0.058)			
	Supplier 1	0.252	3	0.678	1	0.467	1	0.358	2	0.432	1	0.254	3	0.343	2
	Supplier 2	0.274	2	0.266	2	0.375	2	0.369	1	0.383	2	0.274	2	0.305	3
	Supplier 3	0.474	1	0.056	3	0.158	3	0.273	3	0.185	3	0.472	1	0.352	1
(No. 4)		(0.433)		(0.090)		(0.214)		(0.145)		(0.040)		(0.078)			
	Supplier 1	0.142	3	0.704	1	0.384	1	0.133	3	0.144	3	0.497	1	0.271	2
	Supplier 2	0.167	2	0.229	2	0.317	2	0.162	2	0.213	2	0.401	2	0.224	3
	Supplier 3	0.691	1	0.067	3	0.299	3	0.705	1	0.643	1	0.102	3	0.505	1
(No. 5)		(0.454)		(0.094)		(0.170)		(0.159)		(0.041)		(0.082)			
	Supplier 1	0.161	2	0.694	1	0.432	1	0.132	3	0.148	3	0.495	1	0.279	2
	Supplier 2	0.140	3	0.239	2	0.383	2	0.162	2	0.211	2	0.402	2	0.219	3
	Supplier 3	0.699	1	0.067	3	0.185	3	0.706	1	0.641	1	0.103	3	0.502	1

Table 7. Results summary of the DHP-weighted approach.

	No. 1		No. 2		No. 3		No. 4		No. 5		Arithmetic		Geometric	
Alternative	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank
Supplier 1	0.238	3	0.220	3	0.343	2	0.271	2	0.279	2	0.270	2	0.270*	2
Supplier 2	0.280	2	0.250	2	0.305	3	0.224	3	0.219	3	0.265	3	0.256	3
Supplier 3	0.482	1	0.530	1	0.352	1	0.505	1	0.502	1	0.474	1	0.474	1

Note: 0.270 is the normalized value. Non-normalized values: Supplier 1 = 0.267; Supplier 2 = 0.254; Supplier 3 = 0.469.

the results without obscuring any differences in opinion. Table 6 highlights the individual preferences for both the Level 2 criteria and the problem as a whole (i.e., Table 6 lists the preferences of all the expert respondents). The numbers in parentheses represent the local weights computed for the following six criteria: quality, maintenance, product warranty, technical transfer, reputation and price. The global weights and rankings are provided in the last two columns.

5. DHP Process for the Case Study

The DHP process output, as shown in Tables 6 and 7, depicts the final judgments of the respondents. This output was obtained only after holding four additional meetings to discuss the intermediate results. The debates that occurred during these conferences were helpful in clarifying the attribute definitions and identifying misunderstandings. In a few instances, well-reasoned arguments persuaded certain individuals to change their positions on a particular problem. This phenomenon occurred more frequently when the advocate was viewed as an expert and was able to offer supporting data. The data in Table 6 reveal highly consistent responses across the group when quality was accorded the highest priority, followed by maintenance, product warranty, technical transfer, reputation, and pricing criteria. The results for the maintenance criteria also revealed a divergence of opinion. Expert 1 was the most forthright in acknowledging maintenance criteria when ranking Supplier 3 by assigning it a very low weight (0.067) relative to that of Supplier 1 (0.681). However, the effects of this assignment were minimal because this respondent also judged the maintenance criteria to be considerably less crucial than the other five criteria. When the corresponding weight (0.119) of Expert 1 is compared with those of Experts 2-5 (0.118, 0.091, 0.090, and 0.094, respectively, in Table 6), it is apparent that Experts 3-5 believed that maintenance is the fourth most crucial criterion. Table 7 summarizes the computations for each DM response (i.e., each expert's response) and presents two collective measures of comparison the arithmetic mean and geometric mean (Aczel and Alsina, 1987; Bard and Sousk, 1990), which were obtained by arithmetically and geometrically averaging the individual responses at each point of comparison to form a

Table 8. Cost-factor components and their units.

Cost-factor components	Range
1. Aircraft tractor acquisition costs	USD $606,060–680,000 per unit
2. Initial spare parts costs	USD $60,000-75,000
3. Maintenance costs	USD $1,000-1,500 per week
4. Technical training costs	USD $300-330 per week
5. Installation of aircraft tractor costs	USD $50,000-56,000
6. Shipment costs	USD $10,000-15,000
7. Service costs	USD $22,000-25,000

Table 9. Attributes of cost-factor components.

	Aircraft tractor supplier		
Cost-factor of components	Supplier 1	Supplier 2	Supplier 3
1. Aircraft tractor acquisition costs	600,000	650,000	680,000
2. Initial spare parts costs	60,000	65000	68,000
3. Maintenance costs	1,100	1,250	1,500
4. Technical training costs	300	315	330
5. Installation costs	50,000	53,000	56,000
6. Shipment costs	10,000	13,000	15,000
7. Service costs	22,000	24,000	25,000
Total (OFCs) (USD$)	743,400	806,565	845,830

composite matrix, followed by calculating the eigenvectors in the standard manner. Both methods yielded highly similar results and rankings. The strongest preference was shown for Supplier 3, followed closely by Supplier 1, and then Supplier 2.

6. Using the ICFM Model for the Case Study

Solving an ATSS problem should involve considering cost factors such as the direct and indirect costs, as well as the strategic benefits of the proposed investment. Technical and customer requirements should also be included to identify the preferred solutions during selection. The cost-factor components and their units for the aircraft tractor suppliers described in this case study were separated into actual cost factors, as shown in Table 8. The costfactors in the table include seven cost items, with both one-time and recurring items. The attributes of the cost components are listed in Table 9 for three different aircraft tractor suppliers, each of which can perform specified AGHS jobs. Bhattacharya et al. (2005) proposed an ICFM mathematical model for combining cost factor components with the importance weights that were identified during the DHP approach analysis. The *SFM* values used in the weighted DHP are the overall scores in Table 7. The *OFM* values were computed from Table 9. The units of *OFC* are USD ($), whereas the *OFM* values are unitless quantities. The choice of values (i.e., the α value represents an objective factor decision weight) is a crucial: this is a decision that is jointly made by the design engineer, production engineer, maintenance engineer and financial manager of TIAS. The choice value depends on the DMs' prioritization of the objective and subjective factors measures. However, the selection procedures in the ATSS problem may delineate different sets of results for various values among the same DHP processes and cost-factor components. In this case, Eq. (3) was used with $\alpha = 0.67$ (as recommended by Bhattacharya et al., 2005). It is critical to note that the selected value of α depends on the DMs' preferences regarding the importance of objective and subjective factor measures. For example, Bhattacharya et al. (2005) used a sensitivity plot to analyze a robot selection problem; they indicated the following:

The appropriate value (α value) of the objective factor decision weight should be selected carefully. The reason why that is the dominance of the SFM_i values will be higher for a higher value of α. On the other hand, the dominance of cost factor components will be greater for a lower value of α, and later, the SFM_i will have a lower priority (p. 3683). Finally, Tables 10 and 11 show the results of the sensitively analysis with Eq. (3) with the suppliers ranked as follows: Supplier 3 (0.421) >> Supplier 1 (0.299) >> Supplier 2 (0.280) (refer to Table 12 for the results of the compared models). This ranking was similar to the findings in Table 7, which shows that Sup-

Table 10. Objective factor decision weight results for DHP with arithmetically & ICFM model.

α	0	0.17	0.27	0.37	0.47	0.57	0.67	0.77	0.87	0.97	1
SI_1	0.357	0.342	0.334	0.325	0.316	0.307	0.299	0.290	0.281	0.273	0.270
SI_2	0.329	0.318	0.312	0.305	0.299	0.293	0.286	0.280	0.273	0.267	0.265
SI_3	0.314	0.341	0.357	0.373	0.389	0.405	0.421	0.437	0.453	0.469	0.474

Note: SI_1: selection index for supplier 1; SI_2: selection index for supplier 2; SI_3: selection index for supplier 3.

Table 11. Objective factor decision weight results for DHP with geometrically & ICFM model.

α	0	0.17	0.27	0.37	0.47	0.57	0.67	0.77	0.87	0.97	1
SI_1	0.357	0.342	0.334	0.325	0.316	0.307	0.299	0.290	0.281	0.273	0.270
SI2	0.329	0.317	0.309	0.302	0.295	0.287	0.280	0.273	0.265	0.258	0.256
SI3	0.314	0.341	0.357	0.373	0.389	0.405	0.421	0.437	0.453	0.469	0.474

Note: SI_1: selection index for supplier 1; SI_2: selection index for supplier 2; SI_3: selection index for supplier 3

Table 12. Results analysis of the comparing models.

Results Analysis	DHP with arithmetically weight	DHP with geometrically weight	DHP with arithmetically & ICFM model	DHP with geometrically & ICFM model
Supplier 1	0.270	0.270	0.299	0.299
Supplier 2	0.265	0.256	0.286	0.280
Supplier 3	0.474	0.474	0.421	0.421

Note: DHP with arithmetically & ICFM model and DHP with geometrically & ICFM model choice the value (α) are 0.67.

Table 13. Relevant information about ATSS projects.

	Supplier 1 Project	Supplier 2 Project	Supplier 3 Project	Targets
Aircraft tractor cost (US$)	743,400	806,565	845,830	743,400
Supplier capacity (Vehicle)	50	30	70	150
NPV-based cash outflow	150,000	220,000	180,000	530,000
NPV-based cash inflow	200,000	280,000	220,000	700,000
NPV-based ROI (US$)	133.33%	127.27%	122.22%	132.08%

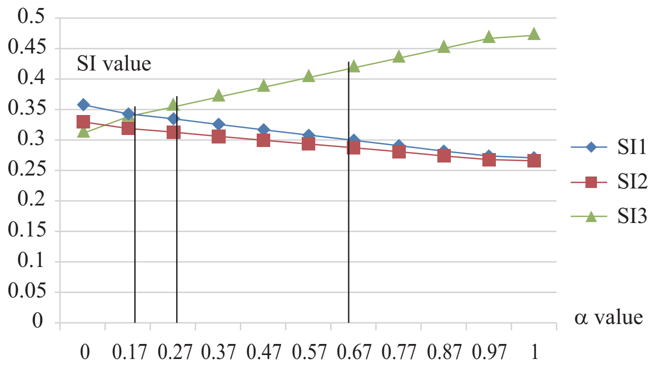

Fig. 3. Sensitivity analysis results for weighted DHP with arithmetic & ICFM model with arithmetic & ICFM model.

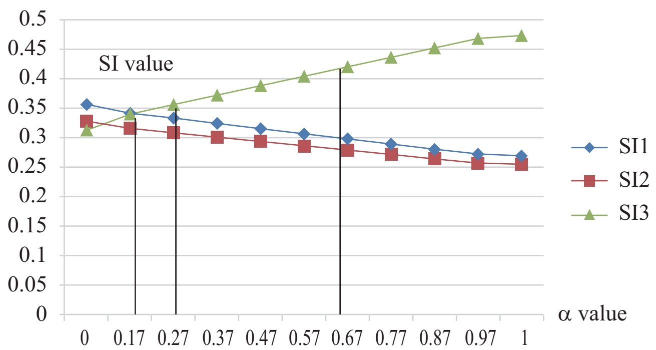

Fig. 4. Sensitivity analysis results for weighted DHP with geometric & ICFM model.

plier 3 is the optimal aircraft tractor supplier (refer to Figs. 3 and 4 and Tables 11 and 12 the sensitivity analysis shows that α = 0.67). Tables 11 and 12 indicate thataccording to the sensitivity analysis, when α = 0, the suppliers are ranked as follows: Supplier 1 > Supplier 2 > Supplier 3. When $0 < \alpha <$ 0.17, the suppliers are ranked as: Supplier 1 > Supplier 3 > Supplier 2. When $0.17 < \alpha < 0.67$, the suppliers are ranked as: Supplier 3 > Supplier 1 > Supplier 2. When $0.67 < \alpha < 1$, the suppliers are ranked as: Supplier 3 > Supplier 1 > Supplier 2. Based on Tables 10 and 11, the *SI* value is nearly the same when $\alpha = 0.67$; thus $\alpha = 0.67$ is the optimal value. Table 12 indicates that Supplier 3 is the optimal choice for the aircraft tractor supplier according to both methods. To evaluate three potential ATSS projects (refer to Table 13) from a financial perspective, the cost factor components of attributes were applied to the MCGP to identify a favorable combination. The five indicators were the aircraft tractor total cost, supplier capacity, NPV-based cash outflow, NPV-based cash inflow, and NPV-based ROI. Specifically, the NPV-based cash outflow was calculated in terms of the total cost of ownership (TCO), which includes all the costs: acquisition cost, initial spare parts cost, maintenance cost, technical training cost, installation cost, shipment cost, and service cost. The NPV-based cash inflow was converted from the benefits of the ATSS project. Subsequently, the NPV-based ROI ratio was calculated by taking the NPV-based cash inflow divided by the NPV-based cash outflow; ROI was represented as a percentage to facilitate judging the ATSS investments. The ATSS investment committee wanted to arrive at a favorable combination of ATSS projects to achieve the expected NPV-based ROI for several goals. Regarding the strategic fitness perspective, the first goal mandates that the ATSS project must be included in the combination because its overall priority was the highest derived from the weighted DHP and ICFM. The second goal dictates that the NPV-based cash inflow must achieve a level of at least US$ 700,000 in 1 year. The third goal requires that NPV-based cash outflow may not exceed US$530,000 yearly. The fourth goal stipulates that the aircraft tractor cost may not exceed US$743,400. The fifth goal allows that the supplier capacity may be in excess of 150 vehicles. The final goal is to consider and utilize the overall priorities of projects derived from the DHP and ICFM model analysis. Hence, the MCGP programming can be expressed as shown in the Appendix I. Under this MCGP programming scheme, the results show that $x_1 = 50$, $x_2 = 30$, $x_3 = 70$, and $y_1 = 743{,}400$. The ATSS projects may accept the solution, because this favorable combination provides NPV-based cash inflow of US$740,000, which exceeds the targeted US$700,000. Additionally, the NPV-based ROI is 139.63% (740,000/530,000), which is higher than the targeted 132.08% (Wu, 2008).

V. CONCLUSIONS

1. Discussion

An appropriate evaluation of the plan and strategies for each alternative is essential for appropriate supplier selection (Bhattacharya and Mukherjee, 2005). This study demonstrated the effectiveness of the ATSS problem-solving approaches. The DHP method was applied to identify the requirement criteria. The ATSS expert team also used DHP to prioritize each aircraft tractor supplier for each criterion. The use of an aircraft tractor supplier by TIAS AGHS was economically justified by incorporating cost factor components into the proposed DHP comparison model. We performed a sensitivity analysis on the proposed model to determine the optimal choice object factor weight value α. This analysis yielded the value of α at which the weighted DHP and ICFM models overlapped in the decision process and provided the confidence level of the decision. Our proposed model produces a single output score that facilitates determining the preferred supplier (Pette and Componation, 2002).

The proposed model led the DMs to consider the involved factors more thoroughly, and provided a systematic method for assigning values to the various criteria involved in making the final decision. Furthermore, the comparison methodology provided decision-making guidance to TIAS AGHS and derived appropriate ATSS processes to satisfy the company's requirements. The DMs must achieve consensus, including consensus on when the available information should be condensed and unstructured. To maximize the efficiency of decision making in this study, cardinal and ordinal factors were considered simultaneously when solving the ATSS problem. In addition, the comparative methodology applied herein offers a sound alternative for solving ATSS problems in unstructured, conflicting, and multi-criteria environments (Bhattacharya and Mukherjee, 2005). Finally, to validate the solution, we adopted an MCGP approach to solve problems arising from the buyers' budget constraints and the suppliers' capacity constraints. The MCGP approach can provide highly suitable results. Thus, our ATSS model could easily be adapted by other AGHS companies for work safety on airside ramp operations and for determining the optimal ATSS.

2. Conclusion

The main contribution of this study is that financial perspectives were applied to accurately calculate the actual costs of aircraft tractors; an appropriate decision method was used to compare the constraints of aircraft tractor supplier capacity and AGHS company budgets to determine the optimal aircraft tractor supplier. We hope our study will provide a new means for considering ATSS from a financial perspective.

3. Future Directions

The proposed comparison model could be extended by integrating genetic algorithms, analytic network processes (ANPs) (Wey and Wu, 2007), fuzzy analytical hierarchy processes (FAHPs) (Chan et al., 2007), data envelopment analysis techniques (Ramanathan, 2007), the preference ranking organization method for enrichment evaluations (Dagdeviren, 2008) and techniques for order performance by similarity to idea solution (TOPSIS) (Wang and Chang, 2007), with the present ICFM model or with some extended the ICFM model (Puniyamoorthy and Ragavan, 2003) for ATSS problem solving; all of these variations may improve the performance of the proposed method and should be considered in future research. In terms of future directions, we can extend the proposed model by combining it with others GP methodologies; this could improve the decision-making framework and could further assist the executive board of AGHS companies in selecting the optimal aircraft tractor supplier.

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