

## **An integrated multiple criteria decision making approach for resource allocation in higher education**

William Ho \*

Operations and Information Management Group

Aston Business School, Aston University

Birmingham B4 7ET, United Kingdom

E-mail: w.ho@aston.ac.uk

\* Corresponding author

Helen E. Higson

Director of Undergraduate Studies

Undergraduate Programme, Aston University

Birmingham B4 7ET, United Kingdom

E-mail: h.e.higson@aston.ac.uk

Prasanta K. Dey

Operations and Information Management Group

Aston Business School, Aston University

Birmingham B4 7ET, United Kingdom

E-mail: p.k.dey@aston.ac.uk

**Abstract:** Resource allocation is one of the major decision problems arising in higher education. Resources must be allocated optimally in such a way that the performance of universities can be improved. This paper applies an integrated multiple criteria decision making approach to the resource allocation problem. In the approach, the analytic hierarchy process (AHP) is first used to determine the priority or relative importance of proposed projects with respect to the goals of the universities. Then, the goal programming (GP) model incorporating the constraints of AHP priority, system, and resource is formulated for selecting the best set of projects without exceeding the limited available resources. The projects include “hardware” (tangible university’s infrastructures), and “software” (intangible effects that can be beneficial to the university, its members, and its students). In this paper, two commercial packages are used: Expert Choice for determining the AHP priority ranking of the projects, and LINDO for solving the GP model.

**Keywords:** higher education; resource allocation; analytic hierarchy process; goal programming; innovation.

**Biographical notes:** William Ho is a Lecturer in the Aston Business School, The Aston University. He obtained BE and PhD degrees from the Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University. His research areas include the applications of operations management and operations research techniques in the printed circuit board assembly, supply chain management/logistics, and higher education management processes.

Helen Higson has worked at Aston University for the past twenty years. She is currently Director of Undergraduate Studies and is Convenor of the School's Research Centre in Higher Education Learning and Management (HELM). Helen is a member of the HEFCE Quality, Learning and Teaching strategic committee.

Prasanta Dey is a Senior Lecturer in the Aston Business School, The Aston University. He has a bachelor of engineering and PhD (engineering) from Jadavpur University, India and a Master's in industrial engineering from Asian Institute of Technology, Thailand. Prior to joining Aston Business School in 2004, he was with the University of the West Indies in Barbados and Indian Oil Corporation Limited in India. He has published extensively in refereed journals like *International Journal of Operations and Production Management*, *International Journal of Production Economics*, *International Journal of Project Management*, *IEEE Transactions on Engineering Management*, *Applied Mathematical Modelling* etc. His current research includes application of multiple criteria decision making in both manufacturing and service industry.

## **1 Introduction**

Resources allocated by governments for higher education have been reduced over the last 30 years due to the public pressure (Lee and Clayton, 1972; Liefner, 2003). According to Liefner (2003), this continuous budget cutting makes universities such as in United Kingdom, United States, and the Netherlands change from traditional state-coordinated systems to market-oriented systems. In other words, the funding scheme is gradually changed from direct government support to performance-related. Managing the process of the higher education system is, therefore, a critical and urgent task for the decision makers of universities to improve their performance (Quaye et al., 2005; Sirca and Sulcic, 2005).

Process management in the market-oriented system is extremely important nowadays. There are four major decision problems: resource allocation, performance measurement, budgeting, and scheduling. Performance measurement was the most commonly studied in the last decade. The subjects measured were the performance of universities (Johnes, 1996; Sarrico et al., 1997; Adcroft and Willis, 2005; Emrouznejad and Thanassoulis, 2005), departments (Sarrico and Dyson, 2000; Al-Turki and Duffuaa, 2003), staff members (Badri and Abdulla, 2004), and students (Stinebrickner and Stinebrickner, 2004). Besides, some researchers incorporated quality into the performance measurement (Kwan and Ng, 1999; Pounder, 1999; Cullen et al., 2003). Comparatively, resource allocation (Watts, 1996; Clarke, 1997; Gillie, 1999; Alho and Salo, 2000; Caballero et al., 2001; Ntshoe, 2003), budgeting (Borgia and Coyner, 1996; McClatchey, 1998; Schmidtlein, 1999; DePillis and DePillis, 2001; Hübner and Rau, 2002; Menash and Werner, 2003), and scheduling (Johnson, 2001; Thompson, 2005) have attracted less attention.

Performance measurement was paid most attention than the others because the funding to most higher education institutions is performance related as mentioned earlier. It is essential for the decision makers to measure their university's performance, including teaching and research, so that they can review and improve their processes based on the benchmarking results. Nevertheless, the performance of all individual members, departments, and universities is highly dependent on how much and how well resource is allocated to them. Resource allocation is definitely a dominant attribute of performance. A system's performance can be enhanced provided that sufficient resource is allocated to the relative important alternatives. Because of gradual cuts in higher education budgeting, resource allocation should be optimized so that the performance of a university can be at least maintained or even superior to its competitors. The lack of appropriate research contributions for optimizing resource allocation is the primary motivation for this paper.

Some quantitative methods like the statistical models (Alho and Salo, 2000; Hübner and Rau, 2002; Mensah and Werner, 2003; Stinebrickner and Stinebrickner, 2004), data envelopment analysis (DEA) (Sarrico et al., 1997; Sarrico and Dyson, 2000; Emrouznejad and Thanassoulis, 2005), multiple regression analysis (Johnes, 1996; Gillie, 1999), stepwise regression analysis (Kwan and Ng, 1999), and differential equations (DePillis and DePillis, 2001) can be applied to aid decision making in higher education. These methods, however, are not suitable for problems with multiple objectives. To overcome this drawback, the multiple criteria decision making (MCDM) techniques should be adopted. It has been found that MCDM techniques can be applied to resource allocation (Caballero et al., 2001), performance measurement (Badri and Abdulla, 2004), budgeting (McClatchey, 1998), and scheduling (Thompson, 2005). Unlike the DEA, which is just suitable for performance measurement, the MCDM techniques are more practical and applicable. Besides, the techniques coincide with real-world situations because the decision problems normally consist of multiple criteria rather than a single objective. Due to these reasons, this paper applies MCDM techniques to the resource allocation problem.

MCDM techniques applied to higher education decision problems in the last decade are the analytic hierarchy process (AHP) (Badri and Abdulla, 2004), and goal programming (GP) (McClatchey, 1998; Caballero et al., 2001; Thompson, 2005). Each of the techniques possesses its own characteristics, and compensates for each other. AHP involves weighing the relative importance or priorities of alternatives of a decision problem accurately, whereas GP is to select the optimal set of alternatives while considering the real-world resource limitations or constraints. Since the optimal decision is dependent on both alternatives' priorities and resource constraints, they should be considered simultaneously or integrated together. This paper, therefore, applies an integrated MCDM approach, which combines both AHP and GP, to tackle the resource allocation problem. The integrated approach has been applied in several areas such as the facility location-allocation problem (Badri, 1999), the quality control systems selection problem (Badri, 2001), and so on. To our knowledge, however, the resource allocation problem in higher education has not been tackled using this technique.

This paper is organized as follows. Section 2 describes the principles of AHP and GP individually, and the procedure of integrated approach. Section 3 determines the priority rankings of proposed alternatives of resource allocation first, and then constructs a GP model for a real-world case study. Section 4 solves the model to optimality, and analyzes the results. Finally, Section 5 concludes the paper.

## 2 Methodology

MCDM techniques are generally divided into two categories: multiple objective decision making (MODM) and multiple attribute decision making (MADM). MODM techniques are a special extension of linear programming. A model is defined as a linear programming when the single objective function and the constraints involve linear expressions, and the decision variables are continuous. But, in MODM techniques, multiple objective functions are incorporated into the model simultaneously. On the other hand, MADM techniques aim at selecting from a population of feasible alternatives which characterized by multiple attributes.

In the following sub-sections, the principles of individual AHP and GP, which are MADM and MODM techniques, respectively, are discussed first. It is then followed by the description of the integrated MCDM approach.

### 2.1 *Analytic hierarchy process*

The AHP, developed by Satty (1980), was found to be the most prevalent MADM technique for dealing with the decision problems in higher education from 1972 to 1995 (Mustafa and Goh, 1996). Basically, the AHP consists of three main operations including hierarchy construction, priority analysis, and consistency verification. First of all, the decision makers need to break down complex multiple criteria decision problems into its component parts of which all possible attributes are arranged into multiple hierarchical levels. For example, overall goal, criteria, attributes of each criterion are in the first, the second, and the third levels, respectively. After that, the decision makers have to compare each cluster in the same level in a pairwise fashion based on their own experience and knowledge. For instance, every two criteria in the second level are compared at each time while every two attributes of the same criteria in the third level are compared at a time. Since the comparisons are carried out through personal or subjective judgments, some degree of inconsistency may occur. To guarantee that the judgments are consistent, the final operation called consistency verification, which is regarded as one of the greatest advantages of the AHP, is incorporated in order to measure the degree of consistency among the pairwise comparisons by computing the consistency ratio (Anderson et al., 2005). If it is found that the consistency ratio exceeds the limit, the decision makers should review and revise the pairwise comparisons. Once all pairwise comparisons are carried out at every level, and are proved to be consistent, the judgments can then be synthesized to find out the priority ranking of each criterion and its attributes.

## 2.2 Goal programming

GP, invented by Charnes and Cooper (1961), is regarded as the most practical MODM technique (Mustafa and Goh, 1996) since it was most frequently used to solve the higher education decision problems. It is indeed very similar to the linear programming model except that multiple goals are taken into consideration at the same time. The goals as well as their priority level (i.e.,  $P_1, P_2, \dots, P_n$ ) are identified by the decision makers. Goals with priority level  $P_1$  are most important, followed by those with priority level  $P_2$ , and so on (i.e.,  $P_1 > P_2 > \dots > P_n$ ). Those with a higher priority level are considered first. Once they have been satisfied that there can be no further improvement, the next most important goals are then considered. Deviation variables (i.e.,  $d_1^+, d_1^-, d_2^+, d_2^-, \dots, d_n^+, d_n^-$ ) are included in each goal equation to represent the possible deviations from goals. Deviation variables with positive signs refer to over-achievement or mean that deviations are above the target value, whereas those with negative signs indicate under-achievement or reflect that deviations are below the target value. The objective function of a GP is to minimize deviations from desired goals. For each goal, there are three possible alternatives of incorporating deviation variables in the objective function, as shown in the following:

- If both over- and under-achievement of a goal is not desirable, then both  $d_i^+$  and  $d_i^-$  are included in the objective function, or
- If over-achievement of a goal is regarded as unsatisfactory, then only  $d_i^+$  is included in the objective function, or
- If under-achievement of a goal is regarded as unsatisfactory, then only  $d_i^-$  is included in the objective function.

The general GP model in the form of mixed integer linear programming can be formulated as follows:

$$\text{Minimize } z = \sum_i P_i (d_i^+ + d_i^-) \quad (1)$$

subject to

$$\sum_j a_{ij} x_j \leq b_i \quad \text{for all } i. \quad (2)$$

$$\sum_j a_{ij} x_j - d_i^+ + d_i^- = b_i \quad \text{for all } i. \quad (3)$$

$$\text{All } x_j = 0 \text{ or } 1; d_i^+, \text{ and } d_i^- \geq 0 \quad (\text{M1})$$

In M1,  $a_{ij}$  is coefficient, whereas  $b_i$  is right-hand side value.  $d_i^+$  and  $d_i^-$  are over-achievement and under-achievement of goal  $i$ , respectively.  $P_i$  is priority level of goal  $i$ . The decision variable of the GP model is denoted as  $x_j$ . The objective function (1) is to minimize the total deviations from the goals, while subjecting to system constraint set (2) and real-world resource constraint set (3). Since all the objective function and constraint sets are in the linear form, M1 belongs to the linear programming type. Besides, decision variables are binary ( $x_j = 0$  or  $1$ ), and deviation variables are continuous ( $d_i^+$  and  $d_i^- \geq 0$ ). M1 is, therefore, regarded as the mixed integer linear programming model (Williams, 1999). After formulating a GP model for a particular decision problem, commercial packages like LINDO and CPLEX can be used to solve the model to optimality. In cases where the model only consists of two decision variables, even the simple graphical method can be adopted.

Badri and Abdulla (2004) pointed out that “good decisions are most often based on consistent judgments”. To prevent inconsistency, the consistency verification operation of the AHP contributes greatly as it acts as a feedback mechanism for the decision makers to review and revise their judgments. Consequently, the judgments made are guaranteed to be consistent, which is the basic ingredient for making good decisions. Nevertheless, the AHP does not consider the limitations of resources in the real-world situations. For this reason, the GP can compensate for the AHP because it makes the optimal decision based on the limited available amount of resources. To provide more and useful information for the decision makers, it is believed that the AHP and GP should be integrated together, and this is the purpose of this paper.

### 2.3 *Integrated approach*

AHP is used to assign priority rankings to proposed alternatives of a MCDM problem, whereas GP is adopted to select the optimal set of alternatives while considering the rankings of alternatives as well as the limitations of resources. Two commercial packages are used in this paper. Expert Choice (version 11) and LINDO (version 6.1) are applied to solve AHP and GP, respectively. The overall procedure of the integrated approach is shown in Figure 1.

In the phase of AHP, the first step is to develop the hierarchy of the problem, that is, resource allocation in this paper, in a graphical representation which helps to illustrate every factor that affects the performance of universities. The hierarchy lists the criteria and their attributes level by level. The highest level of the hierarchy is the goal or problem to be solved. The criteria and attributes are in the second and third levels, respectively.

Constructing a pairwise comparison matrix is intended to derive the accurate ratio scale priorities. The relative importance of two criteria is examined at a time. A judgment is made about which is more important and by how much. Besides criteria, every two attributes of each criterion are compared at a time. The priorities can be represented by numerical, verbal, and graphical judgments. Subjective judgment can be depicted using quantitative scales which are usually divided into 9-point scale in order to enhance the transparency of decision making process. In verbal judgment, preference of “equally preferred” is given a numerical rating of 1, whereas preference of “extremely preferred” is given a numerical rating of 9.

Synthesization is carried out after all the judgments have been determined together with all the comparisons have been made. Expert Choice (version 11) includes two synthesis modes: ideal and distributive. The ideal synthesis mode assigns the full priority of each criterion to its corresponding best (highest priority) attribute. The other attributes of the same criterion receive priorities proportionate to their priorities relative to the best attribute. The priorities for all the attributes are then normalized so that they sum to one. When using this mode, the addition or removal of “not best” attributes will not affect the relative priorities of other attributes under the same criterion. The distributive synthesis mode distributes the priority of each criterion to its corresponding attributes in direct proportion to the attributes’ priorities. When using this mode, the addition or removal of an attribute results in a re-adjustment of the priorities of the other attributes such that their ratios and ranks can change and affect the priorities of the other attributes.

Consistency tests will be conducted to ensure that the result is accurate and reliable, and all judgments are tested and evaluated so as to have a satisfactory result. The principal eigenvalue, which is used to calculate the consistency of judgments, captures the rank inherent in the judgments within a tolerable range. In general, the judgments are considered reasonably consistent provided that the consistency ratio is less than 0.1.

After all criteria and their corresponding attributes are compared together with all judgments are proved to be consistent, the overall priority ranking can be computed. Based on each attribute’s priority and its corresponding criterion priority, the individual priority is summed to calculate the overall priority ranking. This is an input for formulating the AHP priority constraints in a GP model.

Before formulating a GP model, some real-world data on coefficient (e.g., how much resource an attribute consumes) and right-hand side value (e.g., how much resource is available) need to be collected. The decision variables in the model are exactly the same as



the attributes defined in the AHP phase. Then, the priority level of each goal is determined. After that, constraints including system, resource, and AHP priority are formulated. In the system constraints, there are no deviation variables, and the inequality signs instead of equality signs are used. These are the differences between the system and resource constraints. Finally, the objective function in terms of minimizing a prioritized function of the deviation variables is developed. The GP model incorporating with AHP priority constraints can be constructed as follows:

$$\text{Minimize } z = \sum_i P_i (d_i^+ + d_i^-) + \sum_k P_k (d_k^+ + d_k^-) \quad (4)$$

subject to

(2), (3), and

$$x_j - d_k^+ + d_k^- = 1 \quad \text{for all } j \quad (5)$$

$$\text{All } x_j = 0 \text{ or } 1; d_i^+, d_i^-, d_k^+, \text{ and } d_k^- \geq 0 \quad (\text{M2})$$

M2 is an extension of M1 since it also includes the AHP priority constraint set (5) besides the system constraint set (2) and resource constraint set (3). The priority level ( $P_k$ ) of deviation variables  $d_k^+$  and  $d_k^-$  is dependent on the priority ranking of decision variable  $j$ , which is obtained in the AHP phase. M2 is better than M1 because it also considers the relative importance of the attributes of the decision problem rather than just focusing on the limitations of real-world resources. This is the major reason why this paper adopts M2 instead of M1, which was used by Caballero et al. (2001).

### 3 Case study

The decision makers of a university running the market-oriented system plan to enhance its competitiveness. They not only wish to increase the teaching and research quality, but also put more effort on consultancy in order to improve its performance. As a consequence, more funding, research grants and contracts can be raised. For this reason, the decision makers have proposed eight projects. The projects can be classified as two groups: “hardware” and “software”. “Hardware” refers to the university’s infrastructures including (i) establishing an industrial centre – especially for students studying the subjects of engineering and hotel management in order for them to acquire knowledge and experience through extensive hands-on training, (ii) establishing a self-learning centre – for students to acquire more and diversified knowledge after lessons, (iii) establishing a management

development centre – for part-time students with work experience to become equipped with knowledge of management at an advanced level, and (iv) establishing a conference theatre – for holding national or international conferences in which university members can acquire new knowledge, share their own knowledge, and generate new knowledge through integration or collaboration with other researchers at the conferences.

“Software” refers to the intangible effects that can be beneficial to the university, its members, and its students. It consists of (v) establishing E-learning systems – for students to do on-line assignments or tests provided by lecturers, discuss with lecturers or other students concerning the module, and so on, (vi) establishing library information systems – for staff members and students to search relevant books, journal articles, conference papers, and other resources efficiently and effectively, (vii) establishing an Intranet portal – for staff members and students to search, browse, and retrieve useful and related information from the Internet, and form a community of practice so that staff members can share knowledge (e.g., best practice in teaching) as well as collaborate with each other virtually (e.g., brainstorming for research projects), and (viii) establishing incentive scheme – for rewarding and motivating staff members who contribute significantly to the university in terms of teaching, research, and consultancy.

In order to select the best projects to be carried out, the decision makers use AHP to consider the relative importance of projects first. They then formulate a GP model while considering the importance of projects and limitations of resources simultaneously. In the current study, the resources are finance, space, and time. It is assumed that the “hardware” projects cannot be carried out simultaneously. For example, the self-learning centre cannot be established unless the construction of the industrial centre is finished. Similarly, “software” projects must be carried out sequentially. For instance, library information systems can be developed after an E-learning system is set up.

### *3.1 AHP priority*

The first step of AHP is to develop a hierarchy of the decision problem. According to the statement of resource allocation problem, the hierarchy is illustrated in Figure 2. The goal is to select the best set of projects. The criteria are the three major visions of the university: teaching, research, and consultancy. Attributes in the third level are the eight proposed projects. After constructing the hierarchy, two criteria are compared at a time with respect to the goal. Once the pairwise comparisons have been made for the three criteria, each decision attribute is compared against each other attribute with respect to their

corresponding criterion at a time. This type of pairwise comparisons is called top-down. On the other hand, the bottom-up pairwise comparison in which judgments are made about the attributes before making judgments about the criteria is also valid. After completion of all pairwise comparisons, Expert Choice (version 11) is used to compute or synthesize the relative priority for each criterion (refer to Table 1), and each attribute (refer to Table 2). The judgments are acceptable because the consistency ratios are all smaller than 0.1. In case all the judgments have been made and priorities have been calculated, an overall priority ranking of attributes is generated (refer to Table 3). According to Table 3, it is noticed that industrial centre plays the most important role in enhancing the performance of the university because it scores the highest weighting (0.191). Besides, from the perspectives of decision makers, management development centre is the least important project since its weighting is the lowest (0.091). The AHP priority rankings are then used in the GP model.

### 3.2 GP model

Before formulating the GP model for the resource allocation problem, data on coefficients and right-hand side value should be collected. Table 4 shows all the necessary data including the types of resources ( $i = 1, 2, \text{ and } 3$ ), the amount of resource  $i$  used by proposed project or attribute  $j$  ( $a_{ij}$ ), and the maximum amount of resource  $i$  ( $b_i$ ). Resource type 1 refers to financial resource, whereas resource types 2 and 3 denote space and time, respectively. Eight binary decision variables are defined, each of which represents a project or attribute. The definition of the decision variables is:

$$x_j = \begin{cases} 1 & \text{if project } j \text{ is selected,} \\ 0 & \text{otherwise.} \end{cases}$$

where

$x_1$  = establishment of industrial centre

$x_2$  = establishment of self-learning centre

$x_3$  = establishment of management development centre

$x_4$  = establishment of conference theatre

$x_5$  = establishment of E-learning system

$x_6$  = establishment of library information system

$x_7$  = establishment of Intranet portal

$x_8$  = establishment of incentive scheme

Once the resource data and decision variables are collected and defined, the system constraints, resource constraints, AHP priority constraints, and objective function can be developed. In the GP model for the research allocation problem, there are nine goals and fifteen constraints, that is, constraint sets (6) to (20). The objective function (21) is to minimize the total deviations from the goals.

System constraints:

Establish at least four projects:

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 \geq 4 \quad (6)$$

Establish at least one “hardware” project:

$$x_1 + x_2 + x_3 + x_4 \geq 1 \quad (7)$$

Establish at least one “software” project:

$$x_5 + x_6 + x_7 + x_8 \geq 1 \quad (8)$$

Resource constraints:

Priority 1: Establish projects not exceeding the available amount of money

$$71,400x_1 + 57,000x_2 + 50,000x_3 + 35,700x_4 + 4,300x_5 + 2,100x_6 + 6,400x_7 + 28,600x_8 - d_1^+ + d_1^- = 150,000 \quad (9)$$

Establish projects not exceeding the available amount of space

$$12,500x_1 + 2,500x_2 + 10,800x_3 + 625x_4 - d_2^+ + d_2^- = 25,000 \quad (10)$$

Establish “hardware” projects not exceeding the available amount of time

$$24x_1 + 6x_2 + 15x_3 + 12x_4 - d_3^+ + d_3^- = 36 \quad (11)$$

Establish “hardware” projects not exceeding the available amount of time

$$6x_5 + 12x_6 + 9x_7 - d_4^+ + d_4^- = 24 \quad (12)$$

AHP priority constraints:

Priority 2: Establish project 1 (according to the AHP priority in Table 3)

$$x_1 - d_5^+ + d_5^- = 1 \quad (13)$$

Priority 3: Establish project 8

$$x_8 - d_6^+ + d_6^- = 1 \quad (14)$$

Priority 4: Establish project 6

$$x_6 - d_7^+ + d_7^- = 1 \quad (15)$$

Priority 5: Establish project 5

$$x_5 - d_8^+ + d_8^- = 1 \quad (16)$$

Priority 6: Establish project 7

$$x_7 - d_9^+ + d_9^- = 1 \quad (17)$$

Priority 7: Establish project 2

$$x_2 - d_{10}^+ + d_{10}^- = 1 \quad (18)$$

Priority 8: Establish project 4

$$x_4 - d_{11}^+ + d_{11}^- = 1 \quad (19)$$

Priority 9: Establish project 3

$$x_3 - d_{12}^+ + d_{12}^- = 1 \quad (20)$$

Objective function:

$$\begin{aligned} \text{Minimize } z = & P_1 (d_1^+ + d_2^+ + d_3^+ + d_4^+) \\ & + P_2 d_5^- + P_3 d_6^- + P_4 d_7^- + P_5 d_8^- \\ & + P_6 d_9^- + P_7 d_{10}^- + P_8 d_{11}^- + P_9 d_{12}^- \end{aligned} \quad (21)$$

#### 4 Result analysis

The GP model is solved using LINDO (version 6.1). When priority level 6 is found to be unachievable, the optimization process is terminated. The optimal solutions are summarized in Table 5. The values of decision variables show that four projects are selected including establishment of an industrial centre ( $x_1 = 1$ ), establishment of E-learning systems ( $x_5 = 1$ ), establishment of library information systems ( $x_6 = 1$ ), and establishment of incentive scheme ( $x_8 = 1$ ). The total amount of money spent for establishing these four projects is £ 106,400 with a slack of £ 43,600. Besides, the total amount of space occupied

is just a half of the maximum, that is, 12,500 m<sup>2</sup>. The total time spent for establishing “hardware” and “software” projects are 24 and 18 months, respectively. Priority level 6 cannot be achieved because of constraint set (12). In case the project of Intranet portal is selected ( $x_7 = 1$ ), the total time spent for establishing “software” projects (27 months) exceeds the limited available time (24 months).

The comparison between AHP priority ranking found in Section 3.1 and the optimal solution of the GP model is illustrated in Table 6. It is noticed that the four most important projects in terms of the contribution to the university’s performance (teaching, research, and consultancy) are selected. This is a very satisfactory result because the selection not only can avoid excess usage of the university’s resources, but also can increase the competitiveness of the university. Because of limited available time for “software” projects, the fifth important project or the project of Intranet portal cannot be selected as mentioned earlier. Nevertheless, there is a slack of financial resource (£43,600). It is adequate for establishing Intranet portal (£6,400). If a delay of three months is acceptable, the fifth important project can be established, too.

## **5 Conclusions**

This paper studied the resource allocation problem in higher education, with the objective of improving the performance of a university. An integrated multiple criteria decision making approach was developed to solve the problem with real-world data. Firstly, an analytic hierarchy approach (AHP) was used to determine the relative importance of the proposed projects with respect to the university’s goals: teaching, quality, and consultancy. Secondly, the relative importance treated as AHP priority constraints were incorporated into the goal programming (GP) model. Based on the AHP priority, system, and resource constraints, the best set of projects was selected including establishment of an industrial centre, establishment of E-learning systems, establishment of library information systems, and establishment of incentive scheme. It was found that the four projects selected are exactly those contributing to the university most.

The major advantage of this integrated approach is that both intangible factors (relative importance of decision alternatives), and tangible factors (limitations of real-world resources) are considered. It is, therefore, believed that this approach must be more practical and applicable than the stand-alone AHP or GP techniques in solving complex decision problems such as supplier selection, facility location selection, and demand forecasting. It is because the optimal decision is dependent on both alternatives’ priorities and resource constraints.

## References

- Adcroft, A. and Willis, R. (2005) 'The (un)intended outcome of public sector performance measurement', *International Journal of Public Sector Management*, Vol. 18, No. 5, pp.386-400.
- Alho, J. M. and Salo, M. A. (2000) 'Merit rating and formula-based resource allocation', *International Journal of Educational Management*, Vol. 14, No. 3, pp.95-100.
- Al-Turki, U. and Duffuaa, S. (2003) 'Performance measures for academic departments', *International Journal of Educational Management*, Vol. 17, No. 7, pp.330-338.
- Anderson, D. R., Sweeney, D. J. and Williams, T. A. (2005) *An Introduction to Management Science: Quantitative Approaches to Decision Making*, Thomson South-Western, Ohio.
- Badri, M. A. (1999) 'Combining the analytic hierarchy process and goal programming for global facility location-allocation problem', *International Journal of Production Economics*, Vol. 62, No. 3, pp.237-248.
- Badri, M. A. (2001) 'A combined AHP-GP model for quality control systems', *International Journal of Production Economics*, Vol. 72, No. 1, pp.27-40.
- Badri, M. A. and Abdulla, M. H. (2004) 'Awards of excellence in institutions of higher education: an AHP approach', *International Journal of Educational Management*, Vol. 18, No. 4, pp.224-242.
- Borgia, C. R. and Coyner, R. S. (1996) 'The evolution and success of budgeting systems at institutions of higher education', *Public Budgeting and Financial Management*, Vol. 7, No. 4, pp.467-492.
- Caballero, R., Galache, T., Gómez, T., Molina, J. and Torrico, A. (2001) 'Efficient assignment of financial resources within a university system. Study of the University of Malaga', *European Journal of Operational Research*, Vol. 133, pp.298-309.
- Charnes, A. and Cooper, W. W. (1961) *Management Models and Industrial Applications of Linear Programming*, John Wiley & Sons, New York.
- Clarke, G. (1997) 'Reassessing resource allocation strategies in higher education: methods for analysis', *International Journal of Educational Management*, Vol. 11, No. 6, pp.286-292.
- Cullen, J., Joyce, J., Hassall, T. and Broadbent, M. (2003) 'Quality in higher education: from monitoring to management', *Quality Assurance in Education*, Vol. 11, No. 1, pp.5-14.
- DePillis, E. G. and DePillis, L. G. (2001) 'The long-term impact of university budget cuts: a mathematical model', *Mathematical and Computer Modelling*, Vol. 33, pp.851-876.

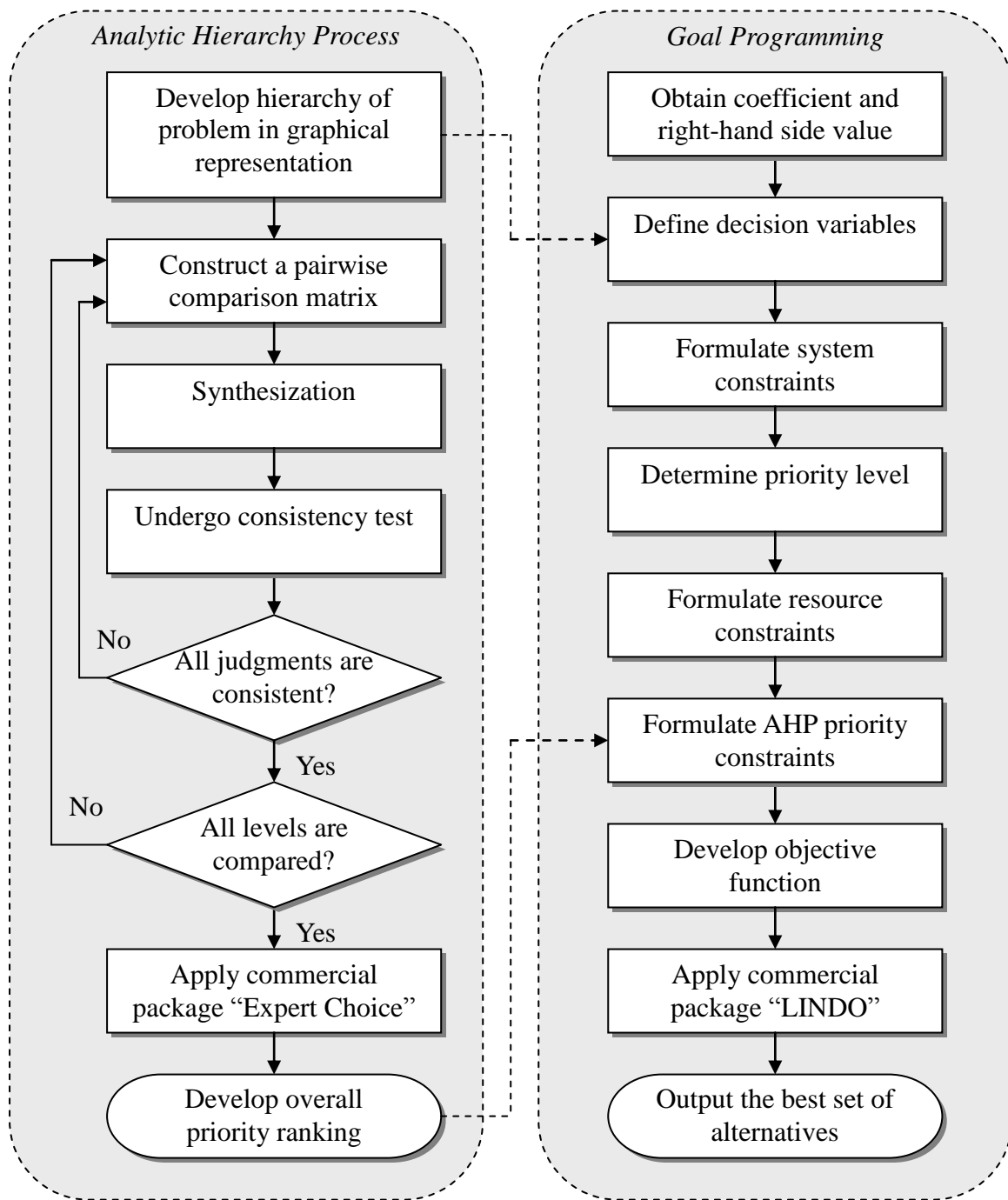
- Emrouznejad, A. and Thanassoulis, E. (2005) 'A mathematical model for dynamic efficiency using data envelopment analysis', *Applied Mathematics and Computation*, Vol. 160, pp.363-378.
- Gillie, A. (1999) 'Efficiency in universities and resource-based learning: a case study of assumptions versus analysis', *Public Money & Management*, July-September, pp.43-49.
- Hübner, P. and Rau, E. (2002) 'Performance budgeting in higher education: the case of the Freie Universität Berlin', *Perspective*, Vol. 6, No. 3, pp.80-86.
- Johnes, J. (1996) 'Performance assessment in higher education in Britain', *European Journal of Operational Research*, Vol. 89, pp.18-33.
- Johnson, D. M. (2001) 'Lessons learned from industry: applying capacity planning in an institution for higher education', *Managerial Finance*, Vol. 27, No. 5, pp.17-32.
- Kwan, P. Y. K. and Ng, P. W. K. (1999) 'Quality indicators in higher education – comparing Hong Kong and China's students', *Managerial Auditing Journal*, Vol. 14, pp.20-27.
- Lee, S. M. and Clayton, E. R. (1972) 'A goal programming model for academic resource allocation', *Management Science*, Vol. 18, No. 8, pp.395-408.
- Liefner, I. (2003) 'Funding, resource allocation, and performance in higher education systems', *Higher Education*, Vol. 46, pp.469-489.
- McClatchey, C. A. (1998) 'A multi-criteria model for optimizing university tuition structures', *Journal of Applied Business Research*, Vol. 14, No. 2, pp.117-128.
- Mensah, Y. M. and Werner, R. (2003) 'Cost efficiency and financial flexibility in institutions of higher education', *Journal of Accounting and Public Policy*, Vol. 22, pp.293-323.
- Mustafa, A. and Goh, M. (1996) 'Multi-criterion models for higher education administration', *Omega, International Journal of Management Science*, Vol. 24, No. 2, pp.167-178.
- Ntshoe, I. M. (2003) 'The political economy of access and equitable allocation of resources to higher education', *International Journal of Educational Development*, Vol. 23, pp.381-398.
- Pounder, J. (1999) 'Institutional performance in higher education: is quality a relevant concept?', *Quality Assurance in Education*, Vol. 7, No. 3, pp.156-163.
- Quaye, A. K. M., Eyob, E. and Ikem, F. (2005) 'Reengineering higher education: the case of an African institution', *International Journal of Innovation and Learning*, Vol. 2, No. 2, pp.111-122.
- Saaty, T. L. (1980) *The Analytic Hierarchy Process*, McGraw-Hill, New York.



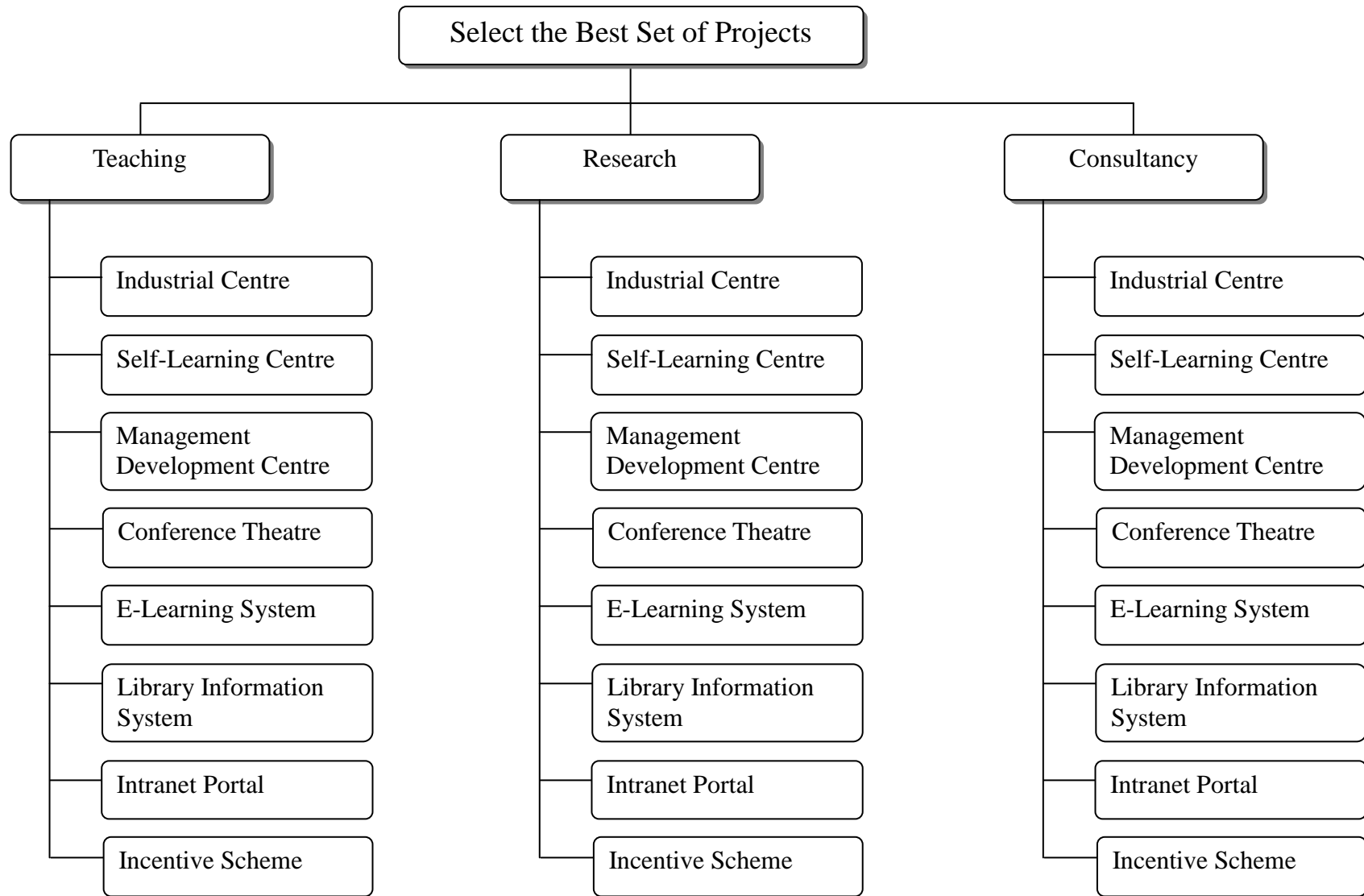
- Sarrico, C. S. and Dyson, R. G. (2000) 'Using DEA for planning in UK universities – an institutional perspective', *Journal of the Operational Research Society*, Vol. 51, pp.789-800.
- Sarrico, C. S., Hogan, S. M., Dyson, R. G. and Athanassopoulos, A. D. (1997) 'Data envelopment analysis and university selection', *Journal of the Operational Research Society*, Vol. 48, pp.1163-1177.
- Schmidtlein, F. A. (1999) 'Assumptions underlying performance-based budgeting', *Tertiary Education and Management*, Vol. 5, No. 2, pp.159-174.
- Sirca, N. T. and Sulcic, V. (2005) 'Lifelong learning: case study in higher education in Slovenia', *International Journal of Innovation and Learning*, Vol. 2, No. 2, pp.142-151.
- Stinebrickner, R. and Stinebrickner, T. R. (2004) 'Time-use and college outcomes', *Journal of Econometrics*, Vol. 121, pp.243-269.
- Thompson, G. M. (2005) 'Using information on unconstrained student demand to improve university course schedules', *Journal of Operations Management*, Vol. 23, pp.197-208.
- Watts, E. W. (1996) 'Internal allocation of funds: changes and challenges for Australian universities', *Financial Accountability & Management*, Vol. 12, No. 1, pp.53-69.
- Williams, H. P. (1999) *Model Building in Mathematical Programming*, John Wiley & Sons, New York.

**Figure 1** The flowchart of the integrated MCDM approach

**Figure 2** The hierarchy of the resource allocation problem



**Figure 1** The flowchart of the integrated MCDM approach



**Figure 2** The hierarchy of the resource allocation problem

**Table 1** Priorities of criteria with respect to goal

**Table 2** Priorities of attributes with respect to criteria

**Table 3** Overall priority ranking of attributes

**Table 4** Resources usage and limitations for the GP model

**Table 5** Optimal solutions of the GP model

**Table 6** Comparison between AHP priority ranking and optimal solution

**Table 1** Priorities of criteria with respect to goal

<b>Criteria</b>	<b>Priorities</b>
Teaching	0.558
Research	0.320
Consultancy	0.122
Total	1.000
<i>Consistency ratio</i>	<i>0.02</i>

**Table 2** Priorities of attributes with respect to criteria

<b>Attributes/Projects (<i>j</i>)</b>	<b>Teaching</b>	<b>Research</b>	<b>Consultancy</b>
1. Industrial Centre	0.254	0.118	0.062
2. Self-Learning Centre	0.160	0.031	0.034
3. Management Development Centre	0.077	0.063	0.224
4. Conference Theatre	0.038	0.207	0.088
5. E-Learning System	0.192	0.032	0.035
6. Library Information System	0.152	0.100	0.113
7. Intranet Portal	0.083	0.158	0.173
8. Incentive Scheme	0.044	0.290	0.271
Total	1.000	1.000	1.000
<i>Consistency ratio</i>	<i>0.03</i>	<i>0.03</i>	<i>0.03</i>

**Table 3** Overall priority ranking of attributes

<b>Attributes/Projects (<i>j</i>)</b>	<b>AHP Priority</b>	<b>AHP Ranking</b>
1. Industrial Centre	0.191	1st
2. Self-Learning Centre	0.107	6th
3. Management Development Centre	0.091	8th
4. Conference Theatre	0.094	7th
5. E-Learning System	0.126	4th
6. Library Information System	0.132	3rd
7. Intranet Portal	0.116	5th
8. Incentive Scheme	0.144	2nd
Total	1.000	
<i>Consistency ratio</i>	<i>0.03</i>	



**Table 4** Resources usage and limitations for the GP model

Resource type (i)	Resource usage of each project ( $a_{ij}$ )								Resource limitations ( $b_i$ )
	$x_1$	$x_2$	$x_3$	$x_4$	$x_5$	$x_6$	$x_7$	$x_8$	
1	71,400	57,000	50,000	35,700	4,300	2,100	6,400	28,600	150,000
2	12,500	2,500	10,800	625	-	-	-	-	25,000
3a	24	6	15	12	-	-	-	-	36
3b	-	-	-	-	6	12	9	-	24

1 = Financial resource (£);

2 = Space resource ( $m^2$ );

3a = Time resource for “hardware” projects (Month);

3b = Time resource for “software” projects (Month).

**Table 5** Optimal solutions of the GP model

<b>Decision Variables</b>	<b>Goal Priority</b>	<b>Achievement</b>	<b>Resource Type</b>	<b>Usage</b>	<b>Slack</b>
$x_1 = 1$	$P_1$	Achieved	Financial	106,400	43,600
$x_2 = 0$	$P_2$	Achieved	Space	12,500	12,500
$x_3 = 0$	$P_3$	Achieved	Time (“hardware”)	24	12
$x_4 = 0$	$P_4$	Achieved	Time (“software”)	18	6
$x_5 = 1$	$P_5$	Achieved			
$x_6 = 1$	$P_6$	Not Achieved ( $d_9^- = 1$ )			
$x_7 = 0$	$P_7$				
$x_8 = 1$	$P_8$				
	$P_9$				

**Table 6** Comparison between AHP priority ranking and optimal solution

<b>Projects</b>	<b>AHP Ranking</b>	<b>GP Model</b>
1. Industrial Centre	1st	Selected
2. Self-Learning Centre	6th	Not selected
3. Management Development Centre	8th	Not selected
4. Conference Theatre	7th	Not selected
5. E-Learning System	4th	Selected
6. Library Information System	3rd	Selected
7. Intranet Portal	5th	Not selected
8. Incentive Scheme	2nd	Selected