Modeling University as a Production Industry: A Quantitative Approach

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***Abstract:* -** Public Institutions of Higher Education (PIHE) are among the most important institutions of learning for a country. Each year, Malaysian government spends a large amount of money to support public universities. Thus, the pressure from the government and the public demanding PIHE to improve cost effectiveness and products quality is very much expected. It is proposed that PIHE operate like production industries which are commercial-based and profit-oriented. The assumption underlies on the premise that production industries operate under efficient management systems, resulting in producing various higher quality products. Nevertheless, no such model is available to be implemented in university settings. Thus, a model of university operating like a production industry is presented in this paper. The constants used are gathered from authentic sources such as Public Service Department and National Accreditation Board. Aspiration levels used are based on Faculty of Science and Technology (FST), *Universiti Pendidikan Sultan Idris*. The proposed model consists of 19 variables which are divided into 2 categories: products and resources. There are 4 objectives and 30 constraints, all of which are converted into goal forms and are arranged into 3 priorities which are in line with Goal Programming (GP) algorithms. Comparison between model solutions and the current practices at FST reveals that the quantity of products and resources at FST are less than the optimum values, except the number of leturer which is higher than the optimum level. The solutions of this model can be used as guidelines for future planning of the faculty.

Key-Words: - Quantitaive approach, Resource Allocation, Goal Programming, Production Industry

1 Introduction

Since the middle of 1960's a great deal of optimization developments have been continuing for allocating resources in university management [7]. The most important reason for this trend was that the managements of the universities faced with tough resource allocation decisions due to limitation of the budgets in certain financial years. The process of allocating resources among competing programs has become increasingly difficult. Consequently, the development of quantitative models to assist in the efficient allocation of college and university resources has generated considerable interest among academic strategists. Since early 1990's, many universities in Britain were corporatized and subsequently followed by Malaysian universities. Corporatization allow universities to borrow money, enter into business, set up companies, and acquire investment shares. Universities are expected to raise funds through a variety of revenue-generating activities such as raising tuition fees, increasing student enrollments, conducting consultancies for industry and government, running short-term courses to meet the needs of private sectors, and renting out facilities. These changes are aimed at developing alternative funding sources for higher education, and reducing the financial dependence on the government. Advocates of the corporatization argue that, with these changes, universities will gain better financial and administrative autonomy. By offering attractive salary packages for academic staff, corporatized universities may prevent the "brain drain" of academics to the private sector. All the university resource allocation models proposed thus far has not been successful in taking these issues into account. Many of these models have not proven to be widely applicable. Problems include lack of actual implementation such as the inability of some models to abstract the multiple and conflicting goals inherent in the academic environment, the over-complexity of some of the models, and the failure of a majority of the models to consider the cognitive limitation of the academic decision maker and the nature of the decision process itself [5].

In 1987, using a survey of 146 articles, White [6] showed that the available models can be implemented in higher education admistration. For a long-range resource planning and budget allocation in the university management, Hopkins [2] developed cost simulation model, where the budget was considered as output of the model rather than input. On the other hand, Schroeder [5] developed a model, where the budget for future planning years have been considered as an input in the model. Basu and Pal [1] used a goal programming model for allocating the budget within the existing academic units in a university in future planning planning period. Their model allocates the budget for the achievement of desired level of teaching staff, non-teaching staff and research fellow. In the model formulation, they used a ratio for promoting the full-time teaching staff to the next higher rank at the successive periods. For such a consideration, a full-time teaching staff employed in certain planning period may be promoted to the next higher rank at the next planning period without considering any eligibility criterion of that higher rank, thereby involving inevitable financial burden. This paper presents a priority based goal programming model for resource allocation in university management for better academic performance, where the operation of university adopted as in the production industry.

2 Model Formulation

The priority based on GP model has been described in detail by Ignizio [3], Lee [4], and others. The general GP model can be represented as:

Minimize lexicographically $z = \sum_{i=1}^{m} P_i \left[w_i \left(d_i^+ + d_i^- \right) \right]$

Subject to

$$\sum_{j=1}^{n} a_{ij} x_j + d_i^- - d_i^+ = b_i$$

x_j , d_i^- , d_i^+ ≥ 0 for all i and *j* with

x_j decision variables

w_i weight for each goal

d_i^- negative deviational variables

d_i^+ positive deviational variables

P_i pre-emptive priority factors

The pre-emptive priority factors (P_i) have the relationship of $P_k >>> P_{k+1}$ where "$>>>$" implies much greater than, i.e., the set of goals at the highest priority level (P_1) must be achieved to the extent possible before the set of goals at the next priority level (P_2) is considered, an so on. w_i are the numerical weights associated with the deviational variables. To formulate the model, the following decision variables and constants are defined.

Decision Variables

a. Products

P_1 : number of graduate courses offered
P_2 : number of undergraduate courses offered
P_3 : number of books published
P_4 : number of journals published
P_5 : number of consultation projects
P_6 : number of inventions
P_7 : number of conferences

b. Resources

S_1 : number of Professors
S_2 : number of Associate Professors
S_3 : number of Senior Lecturers
S_4 : number of Lecturers
S_5 : number of technical staffs
S_6 : number of administrative staffs
S_7 : number of research assistants
S_8 : number of large-scale researches
S_9 : number of medium-scale researches
S_{10} : number of small-scale researches
S_{11} : number of computers
S_{12} : number of reference books

Constants

	Coefficients in the objective functions	
ρ_1	average number of graduate students per course	20
ρ_2	average number of undergraduate students per course	180
ρ_3	average number of copies sold per book	1000
ρ_4	average number of copies sold per journal	500
ρ_7	average number of participants per conference	400
α_1	average tuition fees per graduate course	RM1000
α_2	average tuition fees per undergraduate course	RM720
α_3	average price per published book	RM30
α_4	average price per published journal	RM25
α_5	average value per consultation	RM20,000
α_6	average value per invention	RM10,000
α_7	average fees per participant of conference	RM300
α_8	average supervision time per graduate student per week	1 hour
α_9	average supervision time per undergraduate student per week	0.5 hours
β_1	average annual salary per Professor	RM143,517

β_2	average annual salary per Associate Professor	RM84,792
β_3	average annual salary per Senior Lecturer	RM64,357
β_4	average annual salary per Lecturer	RM45,465
β_5	average annual salary per technical staff	RM15, 467
β_6	average annual salary per administrative staff	RM15, 419
β_7	average annual salary per research assistant	RM17,028
β_8	average cost per large-scale research	RM40, 000
β_9	average cost per medium-scale research	RM30, 000
β_{10}	average cost per small-scale research	RM10, 000
β_{11}	average price per computer	RM4, 500
β_{12}	average price per reference book	RM350
β_{13}	percentage of graduate students need supervision	100%
β_{14}	percentage of undergraduate students need supervision	25%
δ_1	average cost of chemicals and lab instruments	RM1.5 million
δ_2	average utility cost	RM190,500
η_1	average number of class per graduate course	1
η_2	average number of class per undergraduate course	3
μ_1	average number of credit hour per graduate course	3
μ_2	average number of credit hour per undergraduate course	3
φ_1	number of graduate students	1119
φ_2	number of undergraduate students	891

Technological Coefficients		
α_{10}	number of computers available at present time	500
α_{11}	number of reference books available at present time	40,000
α_{12}	average number of articles per journal	10
θ_1	ratio of academic staff to non-academic staff	3:2
θ_2	ratio of computer to graduate student	1:2
θ_3	upper limit of computer desired	600
θ_4	ratio of reference book to student	20:1
θ_5	upper limit of reference books desired	400
θ_6	total budget for salary, medium and small-scale research, buying reference books, computers, chemical and lab instruments, and utility.	RM10.2 million
θ_7	ratio of graduate to undergraduate course	2:3
θ_8	lower limit of large-scale research	8 projects
θ_9	upper limit of teaching load per academic staff per week	12 hours
θ_{10}	upper limit of supervision load per academic staff per week	15 hours
θ_{11}	ratio of book per academic staff	1 : 2
θ_{12}	ratio of journal article per academic staff	1:1
θ_{13}	ratio of journal article per research	3:2
θ_{14}	ratio of invention per research	1:3
θ_{15}	ratio of graduate student per large-scale research	1:1
θ_{16}	ratio of Professor to academic staff	1:10
θ_{17}	ratio of Associate Professor to academic staff	1:5
θ_{18}	ratio of Senior Lecturer to academic staff	2:5
θ_{19}	ratio of academic staff to technical staff	1:1

θ_{20}	ratio of academic staff to administrative staff	10:1
θ_{21}	ratio of academic staff to research assistant	3:1
θ_{22}	total budget for medium and small-scale research	RM2.3 million
θ_{23}	lower limit of invention	15
θ_{24}	lower limit of consultation	10
θ_{25}	lower limit of technical staff	48
θ_{26}	lower limit of administrative staff	8
θ_{27}	lower limit of medium-scale research	3 projects
θ_{28}	lower limit of small-scale research	40 projects
θ_{29}	lower limit of undergraduate course	45
θ_{30}	lower limit of conference	5

Aspirational Levels		
θ_{31}	total profit desired	RM4 million
θ_{32}	lower limit of teaching load per academic staff per week	3 hour
θ_{33}	lower limit of supervision load per academic staff per week	1 hour
θ_{34}	percentage of large-scale research from total research	1/6 = 16.7%

Objectives

(1) Maximize profits

$$maximize\left(\sum_{i=1}^{4}(\rho_i\alpha_i P_i)+\sum_{i=5}^{6}(\alpha_i P_i)+\rho_7\alpha_7 P_7 - \sum_{i=1}^{12}(\beta_i S_i)-\delta_1-\delta_2\right)$$

(2) Maximize the use of academic staffs for teaching

$$maximize\left[\frac{\sum_{i=1}^{2}\eta_i\mu_i P_i}{\sum_{i=1}^{4}S_i}\right]$$

(3) Maximize the use of academic staffs for supervising

$$maximize\left[\frac{\beta_{13}\alpha_8\varphi_1+\beta_{14}\alpha_9\varphi_2}{\sum_{i=1}^{4}S_i}\right]$$

(4) Maximize the percentage of large-scale researches

$$maximize\left(\frac{S_8}{S_8+S_9+S_{10}}\right)$$

Constraints

(1) Ratio of academic staffs to non-academic staffs

$$\frac{\sum_{i=1}^{4}S_i}{\sum_{i=5}^{6}S_i}\geq\theta_1$$

(2) Ratio of computers to the graduate students

$$\frac{\alpha_{10}+S_{11}}{\varphi_1}\geq\theta_2$$

(3) Total number of computers

$$S_{11}\leq\theta_3$$

(4) Ratio of reference books to students

$$\frac{\alpha_{11}+S_{12}}{\sum_{i=1}^{2}\varphi_i}\geq\theta_4$$

(5) Total number of reference books

$$S_{12}\leq\theta_5$$

(6) Total budget for medium and small-scale researches, buying books, computers, chemicals and lab instruments, and utilities

$$\sum_{i=1}^{7}(\beta_i S_i)+\sum_{i=9}^{12}(\beta_i S_i)+\delta_1+\delta_2\leq\theta_6$$

(7) Ratio of graduate courses to undergraduate courses

$$\frac{P_1}{P_2}\geq\theta_7$$

(8) The number of large-scale researches

$$S_8\geq\theta_8$$

(9) Teaching loads

$$\frac{\sum_{i=1}^{2}\eta_i\mu_i P_i}{\sum_{i=1}^{4}S_i} \leq \theta_9$$

(10) Supervising loads

$$\frac{\beta_{13}\alpha_8\varphi_1 + \beta_{14}\alpha_9\varphi_2}{\sum_{i=1}^{4}S_i} \leq \theta_{10}$$

(11) Ratio of books published per academic staff

$$\frac{P_3}{\sum_{i=1}^{4}S_i} \geq \theta_{11}$$

(12) Ratio of journal articles published per academic staff

$$\frac{\alpha_{12}P_4}{\sum_{i=1}^{4}S_i} \geq \theta_{12}$$

(13) Ratio of journal articles per research

$$\frac{\alpha_{12}P_4}{\sum_{i=8}^{10}S_i} \geq \theta_{13}$$

(14) Ratio of inventions per research

$$\frac{P_6}{\sum_{i=8}^{10}S_i} \geq \theta_{14}$$

(15) Ratio of graduate students per large-scale research

$$\frac{\varphi_1}{S_8} \geq \theta_{15}$$

(16) Ratio of Professors to academic staff

$$\frac{S_1}{\sum_{i=1}^{4}S_i} \geq \theta_{16}$$

(17) Ratio of Associate Professors to academic staff

$$\frac{S_2}{\sum_{i=1}^{4}S_i} \geq \theta_{17}$$

(18) Ratio of Senior Lecturers to academic staff

$$\frac{S_3}{\sum_{i=1}^{4}S_i} \geq \theta_{18}$$

(19) Ratio of academic staffs to technical staff

$$\frac{\sum_{i=1}^{4}S_i}{S_5} \geq \theta_{19}$$

(20) Ratio of academic staffs to administrative staff

$$\frac{\sum_{i=1}^{4}S_i}{S_6} \geq \theta_{20}$$

(21) Ratio of academic staffs to research assistant

$$\frac{\sum_{i=1}^{4}S_i}{S_7} \geq \theta_{21}$$

(22) Budget for medium and small-scale researches

$$\sum_{i=9}^{10}(\beta_i S_i) \leq \theta_{22}$$

(23) The desired number of inventions

$$P_6 \geq \theta_{23}$$

(24) The desired number of consultations

$$P_5 \geq \theta_{24}$$

(25) The desired number of technical staffs

$$S_5 \geq \theta_{25}$$

(26) The desired number of administrative staffs

$$S_6 \geq \theta_{26}$$

(27) The desired number of medium-scale researches

$$S_9 \geq \theta_{27}$$

(28) The desired number of small-scale researches

$$S_{10} \geq \theta_{28}$$

(29) The desired number of undergraduate courses

$$P_2 \geq \theta_{29}$$

(30) The desired number of conferences

$$P_7 \geq \theta_{30}$$

2.1 Overall Model

Minimize lexicographically

$$a = \begin{pmatrix} \eta_1 + \eta_2 + \rho_3 + \eta_4 + \rho_5 + \rho_6 + \eta_7 + \eta_8, \rho_9 + \eta_{10} \\ + \eta_{11} + \eta_{12} + \eta_{13} + \eta_{14} + \rho_{15} + \eta_{16} + \eta_{17} + \eta_{18} + \eta_{19} \\ + \eta_{20} + \eta_{21} + \rho_{22} + \eta_{23} + \eta_{24} + \eta_{25} + \eta_{26} + \eta_{27} + \eta_{28} \\ + \eta_{29} + \eta_{30}, \eta_{31} + \eta_{32} + \rho_{33} + \eta_{34} \end{pmatrix}$$

Subject to:

$$S_1 + S_2 + S_3 + S_4 - 6S_5 - 6S_6 + \eta_1 - \rho_1 = 0$$
$$S_{11} + \eta_2 - \rho_2 = 59.5$$
$$S_{11} + \eta_3 - \rho_3 = 600$$
$$S_{12} + \eta_4 - \rho_4 = 200$$
$$S_{12} + \eta_5 - \rho_5 = 400$$

$$\begin{aligned} &143517S_1 + 84792S_2 + 64357S_3 + 45465S_4 \\ &+ 15467S_5 + 15419S_6 + 17028S_7 + 30000S_9 \\ &+ 10000S_{10} + 4500S_{11} + 350S_{12} + 1500000 \\ &+ 190500 + \eta_6 - \rho_6 = 10200000 \end{aligned}$$

$$3P_1 - 2P_2 + \eta_7 - \rho_7 = 0$$
$$S_8 + \eta_8 - \rho_8 = 8$$
$$1P_1 + 3P_2 - 4S_1 - 4S_2 - 4S_3 - 4S_4 + \eta_9 - \rho_9 = 0$$
$$S_1 + S_2 + S_3 + S_4 + \eta_{10} - \rho_{10} = 82$$
$$2P_3 - S_1 - S_2 - S_3 - S_4 + \eta_{11} - \rho_{11} = 0$$
$$10P_4 - S_1 - S_2 - S_3 - S_4 + \eta_{12} - \rho_{12} = 0$$
$$20P_4 - 3S_8 - 3S_9 - 3S_{10} + \eta_{13} - \rho_{13} = 0$$
$$3P_6 - S_8 - S_9 - S_{10} + \eta_{14} - \rho_{14} \geq 0$$
$$S_8 + \eta_{15} - \rho_{15} = 1119$$
$$9S_1 - S_2 - S_3 - S_4 + \eta_{16} - \rho_{16} = 0$$
$$-S_1 + 4S_2 - S_3 - S_4 + \eta_{17} - \rho_{17} = 0$$
$$-2S_1 - 2S_2 + 3S_3 - 2S_4 + \eta_{18} - \rho_{18} = 0$$
$$S_1 + S_2 + S_3 + S_4 - S_5 + \eta_{19} - \rho_{19} = 0$$
$$S_1 + S_2 + S_3 + S_4 - 10S_6 + \eta_{20} - \rho_{20} = 0$$
$$-S_1 - S_2 - S_3 - S_4 + 3S_7 + \eta_{21} - \rho_{21} = 0$$
$$30000S_9 + 10000S_{10} + \eta_{22} - \rho_{22} = 2300000$$
$$P_6 + \eta_{23} - \rho_{23} = 15$$
$$P_5 + \eta_{24} - \rho_{24} = 10$$
$$S_6 + \eta_{26} - \rho_{26} = 8$$
$$S_9 + \eta_{27} - \rho_{27} = 3$$
$$S_{10} + \eta_{28} - \rho_{28} = 40$$
$$P_2 + \eta_{29} - \rho_{29} = 45$$
$$P_7 + \eta_{30} - \rho_{30} = 5$$

$$\begin{aligned} &20000P_1 + 129600P_2 + 30000P_3 + 12500P_4 \\ &+ 20000P_5 + 10000P_6 + 120000P_7 - 143517S_1 \\ &- 84792S_2 - 64357S_3 - 45465S_4 - 15467S_5 \\ &- 15419S_6 - 17028S_7 - 40000S_8 - 30000S_9 \\ &- 10000S_{10} - 4500S_{11} - 350S_{12} - 1500000 \\ &- 190500 + \eta_{31} - \rho_{31} = 4000000 \end{aligned}$$

$$3P_1 + 9P_2 - 3S_1 - 3S_2 - 3S_3 - 3S_4 + \eta_{32} - \rho_{32} = 0$$
$$S_1 + S_2 + S_3 + S_4 + \eta_{33} - \rho_{33} = 1230$$

$$5S_8 - S_9 - S_{10} + \eta_{34} - \rho_{34} = 0$$

P_i, S_i, η_j, ρ_j ≥ 0 for all i and j.

3 Results and Discussion

The model was solved using Goal Programming. Table 1 reveals the solution values for the decision variables and the current practices at FST.

Variables		Current Practice at FST	Model's Results
P_1	# of graduate courses	32	55
P_2	# of undergraduate courses	83	83
P_3	# of books published	12	42
P_4	# of journals published	0	8
P_5	# of consultations projects	3	10
P_6	# of inventions	8	17
P_7	# of conferences	3	5

S1	# of Professors	4	8
S2	# of Associate Professors	7	17
S3	# of Senior Lecturers	0	37
S4	# of Lecturers	47	22
S5	# of technical staffs	20	48
S6	# of administrative staffs	7	8
S7	# of research assistants	5	28
S8	# of large-scale researches	2	9
S9	# of medium-scale researches	1	3
S10	# of small-scale researches	23	40
S11	# of computers	43	60
S12	# of reference books	142	200

Table 1 reveals that the current practices at FST are way below optimum. Among the faculty's products (P_1–P_7), the number of undergraduate courses (83 courses) is the only one that is optimum. For the rest of the products, FST produces less than its optimum level. FST needs to offer 23 more graduate courses, publish 30 more books, publish 8 academic journals, engage in 7 more consultation projects, produce 9 more inventions, and organize 2 more conferences. In reference to the number of academic staffs, the number of existing staffs at FST are not sufficient at all level except Lecturers. FST needs 4 more Professors, 10 Associate Professors, and 37 Senior Lecturers. On the other hand, FST has extra 25 Lecturers. Existing non-academic staffs are also below optimum level. FST still needs 28 technical staffs, 1 administrative staffs and 23 research assistants.

In the formulation of the model, researches are divided into three categories. One of them is the large-scale research. This kind of research is mostly sponsored by outside organisation like IRPA or various industries. Based on the model's result, FST needs to carry out 7 more large-scale researches. The other two research categories are financed internally (using university money). They are medium-scale research (receiving budget from RM30,000 to RM10,000) and small-scale research (receiving budget less than RM10,000). FST needs to carry out 2 more medium-scale researches and 17 more small-scale researches. With the increased usage of ICT in today's university settings, university need to prepare ample number of computers for student use. FST needs to supply 17 more computers to students computer lab. Reference books need to be bought to be used by students and staffs. FST needs to buy 58 more reference books to be placed in the library or in the resource rooms.

4 Conclusion

By treating related variables at the university as products and allocating the resources using lexicographic goal programming technique, the model has demonstrated that goal programming approach can be implemented in the university resource allocation strategy. The model can be used as a tool in helping university plans its future administration allocation where the operation of university is adopted as in the production industry.

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