OPTIMUM ALLOCATION OF RESOURCES IN HOSPITALS THROUGH MULTI CRETERIA DECISION MAKING MODEL

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ABSTRACT

The purpose of this paper is to develop a multi-criteria decision-making model which aids in planning effective resource allocation pertinent to a health-care system. This paper will be approached by using an integrated multi-criteria decision-making model. The proposed model combines goal programming (GP) too in order to solve the problem of satisfying the resource allocation of a health-care system, while meeting the given constraints. The proposed model utilizes the goal programming approach to reflect the multiple, conflicting goals of the health-care system. The proposed model provides the compromised and satisfying solution for planning effective resource allocation.

Key words: Multi-criteria analysis; multi-criteria decision making; multi-criteria decision analysis, goal programming, analytic hierarchy process.

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1. Introduction

As economic units of production systems, health-care system face the problem of planning, controlling, and evaluating resource allocation decisions that consists of multi-criteria, multi-objective, and multi-dimensions. Multi-criteria decision-making (MCDM), an important sub-field of operations research/ management science, is defined as a mathematical model for a decision process which allows the decision-maker to evaluate various competing alternatives to achieve certain goals. This is done by evaluating them along with common multiple criteria. Relative importance is assigned to the goal with respect to criteria. That is, MCDM is appropriate for situations in which the decision-maker needs to consider multiple criteria in arriving at the best overall decision. In MCDM, a decision-maker is to select among a number of alternatives that he evaluates on the basis of two or more criteria. The alternatives can involve risks and uncertainties, they may require sequential actions at different times and the set of alternatives might be either finite or infinite. A decision-maker acts to maximize a value or utility function that depends on the criteria. Since MCDM assumes that a decision-maker is to select among a set of alternatives, its objective function values are known with certainty. Many MCDM problems are formulated as multiple objective linear, integer, non-linear, and/or interactive mathematical programming problems. A number of multi-criteria methods represent viable candidates to employ for selecting the best alternatives. These include analytic hierarchy process (AHP), compromise programming (CP). Goal programming (GP), multi-attribute utility theory (MAUT), and games. **Ahsan et al. [2004]** have developed monitoring healthcare performance by analytic hierarachy process: A developing country perspective. **Carter et al. [1999]** have developed analysis of three decision-making methods: A breast cancer patient as a model. **Chatburn et al. [2001]** have developed decision analysis for large capital purposes: How to buy a ventilator. **Dey et al. [2004]** have developed performance measurement of intensive care services in hospitals: The case of Barbados. **Eckman et al. [1989]** have developed a counterpoint to the analytic hierarchy process. **Hariharan et al. [2004]** have developed a new tool for measurement of process-based performance of multispecialty tertiary care hospitals. **Kwak et al. [2002]** have developed business process reengineering for health-care system using multicriteria mathematical programming. **Longo et al. [2002]** have developed organization of operating theatres: An Italian benchmarking study. **Singh et al. [2006]** have developed optimal management of adults with pharyngitis- A multi-Criteria decision analysis. **Slone et al. [2002]** have developed]: Medical decision support using AHP. **Slone et al. [2003]** have developed using AHP as a clinical engineering tool to facilitate an iterative, multidisciplinary, microeconomic health technology assessment. **Turri et al. [1998]** have developed program eases decision making. **Weingarten et al. [1997]** have developed a pilot study of the use of AHP for the selection of surgery residents. **Winkler et al. [1990]** have developed Decision Modeling and rational choice, AHP and utility theory.

2. Data of the problem

The data utilized to formulate the GP model was collected from the health-care system located in Hyderabad being studied. Group decision-makers involved in the strategic planning process in the health-care system identifies the necessary goals and criteria. These identification of the goals and criteria are derived from the proposal for strategic planning of the health-care system. This proposal has primary goals and sub-goals along with the detailed explanations for the strategic planning. Other necessary information is gathered through a budget allocation proposal, information technology services department, the personnel department of the health-care system. Additional data to the establishment of the health-care resource allocation model is collected from through directors of each department who supervise its own sub-system. The data validation was completed by decision-makers in the current resource allocation process of the health-care system.

The success of the model is based on the accurate measurement of the goals and criteria established by the decision-makers in the health-care system. To complete the validation, the results of both prioritization and the goals and the related projects/alternatives were reviewed by the decision-makers involved in the current resource allocation process of the health-care system. After the data table was developed, the currently available top decision-makers reviewed the data set and provided the validation for the data. Technical and/or managerial terms for the goals and criteria have been changed in terms of their own planning purpose. The strategic planning development committee developed and reviewed the on-going strategic planning proposal and changed the strategic planning proposal. The required information is given in the following tables

Table 1: Project Categories And Available Budgets

Resource Usage (Rs 000)				
Project Category	Year 1	Year 2	Year 3	Available Budget
X_1	400	500	600	1500
X_2	50	60	0	110
X_3	145	60	40	245
X_4	60	60	90	210
X_5	0	20	0	20
Total	655	700	730	2085

Table 2: Annual Cost And Human Resources On Network Alternatives

Resource Usage (Rs 000)			
Network Alternatives	Structure	Supporter	System
Type 1 (X_6)	120	85	60
Type 2 (X_7)	130	90	50
Type 3 (X_8)	130	90	50
Type 4 (X_9)	130	60	55
Available Budget	160	110	70

Table 3: Available Human Resource In Each Department

Available Requirement				
Dept. / Human Resource	Emergency (q = 1)	Radiology (q = 2)	Nuclear Med. (q = 3)	Total
Physician	9	16	14	39
Nurse	32	-	-	32
Technician	-	64	28	92
Total	41	80	42	163

Table 4: Initial Target Level Of Personnel Scheduling

Available Human Resources (Persons)						
Dept. / Time period	Emergency		Radiology		Nuclear Med.	
	Phy.	Nur.	Phy.	Tec.	Phy.	Tec.
Shift 1	3	8	15	37	7	15
Shift 2	5	13	2	17	5	9
Shift 3	3	8	0	12	3	3

Table 5: Annual Salary Of Each Human Resource

Annual Salary (Rs 000)		
Physician	Nurse	Technician
90	34	28

The total annual budget (B_T) is Rs 37, 15,000.

3. Goal Programming Model

3.1 The Model

The generalized linear goal programming model can be stated as :

$$\text{Minimize: } Z = \sum_{k=1}^{k}\sum_{i=1}^{m} w_i p_k (d^-_i + d^+_i)$$

Subject to :

$$\sum_{i=1}^{m} a_{ij}x_j + d^-_i - d^+_i = b_i \quad (j = 1, 2, 3,\ldots\ldots.n)$$

$$x_j , d^-_i, d^+_i \geq 0, \; (i = 1, 2, 3, \ldots\ldots.m; j = 1, 2, 3, \ldots\ldots\ldots n)$$

where

z = the sum of the weighted deviational variables

w_i = the relative weight assigned to the i^{th} goal constraint.

P_k = the k^{th} preemptive priority

d^-_i = a negative deviational variable describing under-achievement of the i^{th} goal.

d^+_i = a positive deviational variable describing over-achievement of the i^{th} goal.

a_{ij} = technical coefficients for the decision variable x.

X_j = decision variable j.

b_i = the right –hand-side value for the i^{th} goal constraint

3.2 Decision Variables:

The integer GP problem consists of three different types of decision variables for this study. First, there are five decision variables for five possible projects to which available amounts can be allocated over three-year period as follows:

X_1 = connectivity project

X_2 = general/ multimedia project

X_3 = micro-computers project

X_4 = instructional media project

X_5 = computing support project

Second, there are four decision variables for different types of network alternatives to be selected with various budgetary and resource constraints as follows:

X_6 = twisted pair-wire either ring, star, bus, or tree topologies

X_7 = base-band coax cable with either bus or tree topologies

X_8 = broad-band coax cable with either bus or tree topologies

X_9 = fiber optic cable with either ring, star, bus, or tree topologies

Third, there are eighteen decision variables related to the human resource allocation as follows:

X_{10} = a number of physician in the emergency department in shift 1 (7am – 3pm)

X_{11} = a number of nurses in the emergency department in shift 1 (7am – 3pm)

X_{12} = a number of physicians in the radiology department in shift 1 (7am – 3pm)

X_{13} = a number of technicians in the radiology department in shift 1 (7am – 3pm)

X_{14} = a number of physicians in the nuclear medicine department in shift 1 (7am – 3pm)

X_{15} = a number of technicians in the nuclear medicine department in shift 1 (7am – 3pm)

X_{16} = a number of physicians in the emergency department in shift 2 (3pm – 11pm)

X_{17} = a number of nurses in the emergency department in shift 2 (3pm – 11pm)

X_{18} = a number of physicians in the radiology department in shift 2 (3pm – 11pm)

X_{19} = a number of technicians in the radiology department in shift 2 (3pm – 11pm)

X_{20} = a number of physicians in the nuclear medicine department in shift 2 (3pm – 11pm)

X_{21} = a number of technicians in the nuclear medicine department in shift 2 (3pm – 11pm)

X_{22} = a number of physicians in the emergency department in shift 3 (11pm – 7am)

X_{23} = a number of nurses in the emergency department in shift 3 (11pm – 7am)

X_{24} = a number of physicians in the radiology department in shift 3 (11pm – 7am)

X_{25} = a number of technicians in the radiology department in shift 3 (11pm – 7am)

X_{26} = a number of physicians in the nuclear medicine department in shift 3 (11pm – 7am)

X_{27} = a number of technicians in the nuclear medicine department in shift 3 (11pm – 7am)

where X_j = nonnegative integers (j = 1, 2, 3, ………..27)

3.3 Objective Function

The objective of the integer GP problem is to minimize the value of the objective function subject to the constraints (1) – (46), satisfying the preemptive priority rules. Among 46 constraints, first seven constraints are system constraints so that they do not require any deviational variables. The priority designation of each goal has been indicated in conjunction with the formulation of each goal constraint. Thus, the objective function depends on the preemptive priority sequence of the goals which have 12 priorities.

The complete objective function summarizes these prioritized goals as follows:

$$\text{Minimize:} \quad z = \sum_{k=1}^{12} \sum_{i=8}^{46} w_i P_k (d^-{}_i + d^+{}_i)$$

These decomposed goals with prioritization will be utilized in the priority assigned to the GP model. These prioritized values are significant for understanding decision- making process for strategic planning of resource allocation in the health-care system under consideration. The use of AHP clearly identifies the health-care system's goal priority. This prioritization will provide decision –makers with more acceptable GP solutions.

3.4 Goal Programming Problem Formulation

The GP model's objective function and constraints are formulated and goal priorities are presented below;

Minimize

$$
\begin{aligned}
z = {} & P_1(d^+{}_8 + d^+{}_9 + d^+{}_{10} + d^+{}_{11}) \\
& + P_2(d^+{}_{12} + d^+{}_{13} + d^+{}_{14}) \\
& + 0.392P_3 d^+{}_{15} + 0.313P_3 d^+{}_{16} + 0.184P_3 d^+{}_{17} \\
& + 0.293P_3 d^+{}_{18} \\
& + P_4(d^-{}_{19} + d^+{}_{19}) \\
& + P_5(d^-{}_{20} + d^+{}_{20}) \\
& + P_6(d^-{}_{21} + d^+{}_{21}) \\
& + P_7(d^-{}_{22} + d^+{}_{22}) \\
& + P_8(d^-{}_{23} + d^+{}_{23}) \\
& + P_9(d^-{}_{24} + d^+{}_{24}) \\
& + P_{10}(d^-{}_{25} + d^+{}_{25}) \\
& + P_{11}(d^-{}_{26} + d^+{}_{26} + d^-{}_{27} + d^+{}_{27} + d^-{}_{28} + d^+{}_{28} \\
& + d^-{}_{29} + d^+{}_{29} + d^-{}_{30} + d^+{}_{30} + d^-{}_{31} + d^+{}_{31} \\
& + d^-{}_{32} + d^+{}_{32} + d^-{}_{33} + d^+{}_{33} + d^-{}_{34} + d^+{}_{34} \\
& + d^-{}_{35} + d^+{}_{35} + d^-{}_{36} + d^+{}_{36} + d^-{}_{37} + d^+{}_{37} \\
& + d^-{}_{38} + d^+{}_{38} + d^-{}_{39} + d^+{}_{39} + d^-{}_{40} + d^+{}_{40} \\
& + d^-{}_{41} + d^+{}_{41} + d^-{}_{42} + d^+{}_{42} + d^-{}_{43} + d^+{}_{43}) \\
& + P_{12}(d^-{}_{44} + d^+{}_{44} + d^-{}_{45} + d^+{}_{45} + d^-{}_{46} + d^+{}_{46})
\end{aligned}
$$

System constraint 1 : select one among four network alternatives.

$$X_6 + X_7 + X_8 + X_9 = 1 \qquad (1)$$

System constraint 2: Assign human resources in each department (q = 1, 2 and 3) in time t (t = 1,2, and 3)

$$X_{10} + X_{16} + X_{22} = 8 \ldots\ldots\ldots\ldots\ldots (2)$$

$$X_{11} + X_{17} + X_{23} = 30 \ldots\ldots\ldots\ldots\ldots (3)$$

$$X_{12} + X_{18} + X_{24} = 15 \ldots\ldots\ldots\ldots\ldots (4)$$

$$X_{13} + X_{19} + X_{25} = 65 \ldots\ldots\ldots\ldots\ldots (5)$$

$X_{14} + X_{20} + X_{26} = 12$…………….(6)

$X_{15} + X_{21} + X_{27} = 24$…………….(7)

Priority 1: provide the health-care system's resources adequately, but

(a) not to exceed the entire budget amount.

$1200X_1 + 90X_2 + 203X_3 + 190 X_4 + 15 X_5 - d^+_8 = 1{,}700$ …(8)

(b) not to exceed the available budget amount in each year.

$300X_1 + 40X_2 + 125X_3 + 50 X_4 - d^+_9 = 515$ ……… ...(9)

$400X_1 + 50X_2 + 50X_3 + 50 X_4 + 15 X_5 - d^+_{10} = 565$…..(10)

$500X_1 + 30X_3 + 90 X_4 - d^+_{11} = 620$ ………………..….(11)

Priority 2: Minimize the total cost to select an adequate network alternative by using:

(a) a total budget for structure of Rs 600(000)

$110X_6 + 120X_7 + 120X_8 + 130 X_9 - d^+_{10} = 600$ ……...(12)

(b) a total budget for supporters of Rs 400(000)

$75X_6 + 80X_7 + 80X_8 + 60 X_9 - d^+_{11} = 400$ ………..…..(13)

(c) a total budget for network system of Rs240(000)

$50X_6 + 50X_7 + 50X_8 + 55 X_9 - d^+_{12} = 240$ …………...(14)

Priority 3: select the optimal network alternatives.

$X_6 + d^-_{15} - d^+_{15} = 1$………..(15)

$X_7 + d^-_{16} - d^+_{16} = 1$………..(16)

$X_8 + d^-_{17} - d^+_{17} = 1$………..(17)

$X_9 + d^-_{18} - d^+_{18} = 1$………..(18)

Priority 4 : Implement connectivity project—project1.

$X_1 + d^-_{19} – d^+_{19} = 1$……………………….(19)

Priority 5: Implement instructional media project--- project 4

$X_4 + d^-_{20} – d^+_{20} = 1$……………………….(20)

Priority 6: implement general/multimedia project –project 2.

$X_2 + d^-_{21} – d^+_{21} = 1$……………………….(21)

Priority 7: Implement micro-computing project—project 3

$X_3 + d^-_{22} – d^+_{22} = 1$……………………….(22)

Priority 8: Implementing computing services support project ---- project 5

$X_5 + d^-_{23} – d^+_{23} = 1$……………………….(23)

Priority 9; Maximize the available payroll budget for human resources.

$70X_{10}+ 33X_{11} +70X_{12} +27X_{13} +70X_{14} +27X_{15}+70X_{16}$
$+33X_{17}+70X_{18}+ 27X_{19}+70X_{20}+27X_{21}$
$+ 70X_{22}+ 33X_{23}+27X_{25} + 70X_{26}+27X_{27}$
$+ d^-_{24} – d^+_{24} = 5,633$…………………………………………………….(24)

Priority 10: maximize the utilization of the existing human resource in order to provide satisfactory health-care services to the patient.

$X_{10}+X_{11} +X_{12} +X_{13} +X_{14} +X_{15}+X_{16}+X_{17}+X_{18}+ X_{19}+X_{20}+X_{21}+ X_{22}+ X_{23}+X_{25} + X_{26}+X_{27}$
$+ d^-_{25} – d^+_{25} = 154$……………………………………………………….(25)

Priority 11: balance the utilization of human resource distribution.

(a) a desired number of physicians in emergency department (q = 1) in shift 1 (X_{10}) , shift 2 (X_{16}), and shift 3 (X_{22})

$X_{10} - 2 + d^-_{26} - d^+_{26} = 0$……………………..(26)

$X_{16} - 4+ d^-_{27} - d^+_{27} = 0$………………..……..(27)

$X_{22} - 2+ d^-_{28} - d^+_{28} = 0$………….…………..(28)

(b) a desired number of nurses in emergency department (q=1) in shift 1 (X_{11}) , shift 2 (X_{17}), and shift 3 (X_{23})

$X_{11} - 9 + d^-_{29} - d^+_{29}= 0$……………………..(29)

$X_{17} - 12 + d^-_{30} - d^+_{30}= 0$…………… ……..(30)

$X_{23} - 9 + d^-_{31} - d^+_{31}= 0$……………………..(31)

(c) a desired number of physicians in radiology department (q=2) in shift 1 (X_{12}) , shift 2 (X_{18}), and shift 3 (X_{24})

$X_{12} - 14 + d^-_{32} - d^+_{32} = 0$……………………..(32)

$X_{18} - 1 + d^-_{33} - d^+_{33} = 0$………………………..(33)

$X_{24} + d^-_{34} - d^+_{34} = 0$……………… ………...(34)

(d) a desired number of technicians in radiology department (q=2) in shift 1 (X_{13}) , shift 2 (X_{19}), and shift 3 (X_{25})

$X_{13} - 14 + d^-_{35} - d^+_{35} = 0$……………………..(35)

$X_{19} - 1 + d^-_{36} - d^+_{36} = 0$……………………..(36)

$X_{25} + d^-_{37} - d^+_{37} = 0$…………………………..(37)

(e) a desired number of physicians in nuclear medicine department (q=3) in shift 1 (X_{14}) , shift 2 (X_{20}), and shift 3 (X_{26})

$X_{14} - 38 + d^-_{38} - d^+_{38} = 0$……………………..(38)

$X_{20} - 16 + d^-_{39} - d^+_{39} = 0$……………………..(39)

$X_{26} - 11 + d^-_{40} - d^+_{40} = 0$……………………..(40)

(f) a desired number of technicians in nuclear medicine department (q=3) in shift 1 (X_{15}) , shift 2 (X_{21}), and shift 3 (X_{27})

$X_{15} - 6 + d^-_{41} - d^+_{41} = 0$……………………..(41)

$X_{21} - 4 + d^-_{42} - d^+_{42} = 0$……………………..(42)

$X_{27} - 2 + d^-_{43} - d^+_{43} = 0$……………………..(43)

Priority 12: Assign appropriately human resources in each department in time t (t = 1, 2 and 3)

(a) a desired number of human resources in shift 1

$X_{10} + X_{11} + X_{12} + X_{13} + X_{14} + X_{15} + d^-_{44} - d^+_{44} = 83$ ……………………(44)

(b) a desired number of human resources in shift 2

$X_{16} + X_{17} + X_{18} + X_{19} + X_{20} + X_{21} + d^-_{45} - d^+_{45} = 45$………………………(45)

(c) a desired number of human resources in shift 1

$X_{22} + X_{23} + X_{24} + X_{25} + X_{26} + X_{27} + d^-_{46} - d^+_{46} = 26$ …………………………(46)

4. RESULT AND ANALYSIS

The integer GP model , presented in the chapter 3, was solved using a QSB + computer software. The possible solutions are enumerated at the first priority level and reduced at each subsequent priority level until overall goal achievement is no longer possible in this GP problem, the solution was determined after 39 iterations. The computer solution yields the following results as shown in Table 6.

Budget allocation goal (G_1) is one of the most important overall goals for the strategic planning of resource allocation in the health-care system. Thus this goal provides GP solutions as follows. Priority 1 is of providing the health-care system's resources adequately, but not to exceed the entire budget amount (d^+_8) and the available budget amount in each year [d^+_9, d^+_{10} and d^+_{11}]. This priority is fully satisfied, since $P_1 = 0$. All related deviational variables were zero.[i.e. $d^+_8 = 0$, $d^+_9 = 0$, $d^+_{10} = 0$, $d^+_{11} = 0$].

Network construction goal (G_1) is dealing with two aspects: P_2-minimize the total cost of network resources and P_3- select the optimal network alternatives.

Table 6: Solution Results

Decision variable	Deviational variable *	Goal priority	Goal achievement
$X_1 = 1$	$d^-_{12} = 40$	P_1	Fully achieved
$X_2 = 1$	$d^-_{13} = 25$	P_2	Fully achieved
$X_3 = 1$	$d^-_{14} = 10$	P_3	Fully achieved
$X_4 = 1$	$d^-_{16} = 1$	P_4	Fully achieved
$X_5 = 1$	$d^-_{17} = 1$	P_5	Fully achieved
$X_6 = 0$	$d^-_{18} = 1$	P_6	Fully achieved
$X_7 = 0$	$d^-_{25} = 3$	P_7	Fully achieved
$X_8 = 0$	$d^-_{32} = 3$	P_8	Fully achieved
$X_9 = 0$	$d^-_{34} = 3$	P_9	Fully achieved
$X_{10} = 2$	$d^-_{44} = 3$	P_{10}	Not achieved
$X_{11} = 9$	$d^-_{46} = 3$	P_{11}	Not achieved
$X_{12} = 11$		P_{12}	Not achieved
$X_{13} = 38$			
$X_{14} = 6$			
$X_{15} = 14$			

X_{16} = 4			
X_{17} = 12			
X_{18} = 1			
X_{19} = 16			
X_{20}= 4			
X_{21}= 8			
X_{22}= 2			
X_{23}= 9			
X_{24}= 3			
X_{25}= 11			
X_{26}= 2			
X_{27}= 2			

*All other deviational variables are zero.

Priority 2 of minimizing the total cost to a specific network construction resources is fully satisfied, since P_2= 0. All positive deviational variables are zero [i.e. d^+_{12}=0,d^+_{13}=0 and d^+_{14} = 0]. But all negative deviational variables are not zero [i.e. d^-_{12}=40,d^-_{13}=25 and d^-_{14}=10]. This means that the negative deviational , d^-_{12}=40, have the savings of Rs 40,000 in the structure, d^-_{13} = 25 , the savings of Rs 25,00 in the supporter; and d^-_{14} = 10 , the savings of Rs 10,000 in the system.

Priority 3 of selecting the optimal network alternatives is fully satisfied, since P_3 = 0. The positive deviational variable d^+_{15} is zero(d^+_{15} = 0], while other positive deviational variables in the priority 3 are not zero[d^+_{16} = 1, d^+_{17} = 1 and d^+_{18} = 1]. There are four decision variables for network alternative types to be considered; X_6 for network alternative type 1; X_7 for network alternative type 2; X_8 for network alternative type3; X_6 for network alternative type 4. among them, the decision variables in the network alternative type 1 is one [X_6 =1]. Thus, network alternative type 1 is selected as the best network alternative for an acceptable network design selection in network construction goal. Other alternatives types 2, 3, and 4 are not selected [X_7 = 0, X_8 = 0 and X_9 = 0].

5. Conclusion

This paper demonstrate the application potential of the proposed intriguer GP model applied to strategic resource allocation planning in a health care system and other similar settings. The most significant aspect of this paper is an application of the goal programming model that can be implemented by organizations to plan the strategic resource allocation. This model provides a practical method for analysis of resource allocation planning identified during the decision making process in a health care system. It can be used to implement successfully large-scale and multi-dimensional planning in a health-care system and other similar settings.

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