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Allocation of Human Resources in a Health Care Organization through Goal Programming

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ABSTRACT

This paper presents the development of a Goal Programming (GP) model as an aid to strategic planning and allocation for limited human resources in a health – care organization. The purpose of this study is to assign the personnel to the proper shift hours that enable management to meet the objective of minimizing the total pay roll costs while patients are satisfied. A GP model is illustrated using the data provided by a health-care organization in the Midwest area. The goals are identified and prioritized. The GP model application adds insight to the planning functions of resources allocation in the health-care organizations. The proposed model is easily applicable to other human resource planning process.

KEY WORDS: GP Model; Health Care; Shift Hours.

INTRODUCTION:

Health-care systems in general are facing extreme pressures to excel in an environment of rapidly changing expectations, exploding global resources needs, and increased financial demands. Achievement of effective resources allocation is both a consequence of and a solution for overcoming these challenges. It is imperative that such systems address the growing requirements for effective resource allocation. Moreover, today's health-care systems are complicated by multiple objectives, multiple evaluation criteria, and multiple decision-makers within the system, while resources and budget are extremely limited.

As the health-care systems react to severe financial pressures, too much emphasis will be often placed on balancing the budget at the expanse of goals of the systems. The critical issue in the management of a health-care is not just financial efficiency. The operation policy must be based on the compromised agreements of the diverse groups within the health-care system. Therefore, a systematic analysis and evaluation to provide competitive advantages for future survival and actions for the goal achievement.

Goal Programming (GP) has been utilized extensively and successfully for the development of a resource allocation decision-making model in business and health-care systems have been limited to using a single functional area, such as nursing scheduling, allocating blood, and clinic site location, financial investment, rather than comprehensive resource allocation aspects.

Management seeks to minimize the total pay roll costs, while maximizing human resources utilization. Therefore, the objective of this study is to present how a specific mathematical programming model can be used to achieve the effective resource allocation of limited human resources in health-care system.

In this paper, a GP model is developed based on the data obtained from a health-care organization in Hyderabad. The model is analyzed and interpreted. This GP model can facilitate planning, decision-making, and managerial control by providing health-care management information.

GP Model:

To develop a GP model the following symbols are used and the model components (system constraints, goal constraints and objective function) are explained below.

Definition of Symbols

X_{jt}^{0} = initial number of physician working in department j in period t.

X_{jt} = total number of physician working in department j in period t.

$\bar{X}_{jt}$ = number of physician desired in the department j in period t.

$\bar{X}_{jt+1}$ = proportion of physician who stay in the dept. j from period t to t+1.

$\bar{X}^{*}_{jt}$ = target proportion of physician in department j in period t.

$\hat{X}_{jt}$ = upper bound on the no. of physician who can work in department j n period t.

X^{1}_{jt} = physicians salary in department j in period t.

Y_{jt} = total no. of nurses working in dept. j in period t.

$\bar{Y}_{jt}$ = proportion of nurses who stay in department j in period t to t+1.

$\bar{Y}^{*}_{jt}$ = target nurse- to – physician ratio in department j in period t.

Y^{1}_{jt} = nurse's salary in department j in period t.

Z_{jt} = total number of technicians working in department j in time t.

$\bar{Z}_{jt}$ = proportion of technicians who stay in department j from period t to t+1.

$\bar{Z}^{*}_{jt}$ = target technician- to – physician ratio in department j in period t.

Z^{1}_{jt} = technician's salary in department j in period t.

B_T = total budget available during period t.

In all cases, unless otherwise specified, t= 1,……………..T; and all variables are non-negative.

System Constraints:

Budget Allocation : The total amount available for pay rolls in limited in total period T, where B_T =5,633,000.

$$\sum_{j=1}^{n}(X^{1}_{jt}X_{jt} + Y^{1}_{jt}Y_{jt} + Z^{1}_{jt}Z_{jt}) \le B_T \quad \text{or} \quad \sum_{j=1}^{n}(70X_{jt} + 30Y_{jt} + 27Z_{jt}) \le 56{,}33{,}000. \text{---[1]}$$

Nurse utilization : at least 50% of nurses in dept. j in period t will stay in period t = 1.

$Y_{jt+1} \geq \bar{Y}_{jt} Y_{jt}$ or $Y_{jt+1} \geq 0.5 Y_{jt}$ --[2]

Technician utilization : at least 50% of technician in dept. j in period t will stay in period t+1.

$Z_{jt+1} \geq \bar{Z}_{jt} Z_{jt}$ or $Z_{jt+1} \geq 0.5 Z_{jt}$ --------------------------------------[3]

Physician utilization : the total number of physician in dept. j in period t+1, plus the initial no. of physicians working in dept. j in period t+1.

$X_{jt+1} = \bar{X}_{jt} X_{jt} + \overset{0}{X}_{jt}$, t = 1,2,………..t-1.

$X_{j1} = X_{j0} + \overset{0}{X}_{jt}$ --- [4] – [6]

Where, $\bar{X}_{jt}, X_{jt}$ is proportion of those whose stay in dept. j from period t to t+1 times the total no. of physicians in dept. j in period t. and X_{j0} is given.

Upper limit for physician utilization: An upper limit of the no. of physicians who can work in dept. j in period t can not be less than no. of physician in that period.

$X_{jt} \leq \hat{X}_{jt}$ --- [7] – [9]

Goal Constraints:

There are five goals in the model.

P1: Minimum payroll Goal (Priority 1)

Achieve the minimum payroll cost for the effective budget planning.

$$\sum_{j=1}^{n} (X_{jt} + Y_{jt} + Z_{jt}) + d_1^- - d_1^+ = 0$$ -- [10]

P_2 : Physician Utilization Goal (Priority 2)

Achieve the proper physician utilization in department j in period t. That is,

$$X_{jt} + d_2^- - d_2^+ = \bar{X}_{jt} \text{ ---------- [11]}$$

P_3 : Physician Assignment Goal (Priority 3)

Achieve the proper proportion of physicians. This goal can be achieved by the total number of physicians in dept. j in period t minus the target proportion of physicians in dept. j in period t times the total no. of physicians in dept. j in period t.

That is,

$$X_{jt} - (\bar{X}^*_{jt})X_{jt} + d_3^- - d_3^+ = 0 \text{ ---------- [12]}$$

P_4 : Nurse Utilization Goal (Priority 4)

Achieve the proper level of assigned nurses based on the target ratio of nurse to physician. This goal can be achieved by total no. of nurses in dept. j in period t minus target ratio of nurse- to - physician time's total no. of physician in dept. j in period t.

$$Y_{jt} - (\bar{Y}^*_{jt})X_{jt} + d_4^- - d_4^+ = 0 \text{ ---------- [13]}$$

P_5 : Technician Utilization Goal (Priority 5)

Achieve the proper level of assigned technicians based on the ratio of technician-to-physician. This goal can be achieved by total no. of technician in dept. j in period t minus target ratio of technician-to-physician times total no. of physicians in dept. j in period t.

That is,

$$Z_{jt} - (\bar{Z}^*_{jt})X_{jt} + d_5^- - d_5^+ = 0 \text{ ---------- [14]}$$

Objective Function

Minimize: Z =

$$\sum_{j=1}^{3}\sum_{t=1}^{6}[P_1(d_1^+) + P_2(d_2^- + d_2^+) + P_3(d_3^- + d_3^+) + P_4(d_4^- + d_4^+) + P_5(d_5^- + d_5^+)]$$

Data of the Problem

Management of health-care systems refers to assign personnel property to each of alternative work scheduled to meet both skill and work force requirements, and also to minimize its total payroll costs. To simplify the problem, three departments of the organization and scheduling. Management wishes to separate the personnel schedule for the emergency, radiology, and nuclear medicine departments. Each department has two types of employees; nurses and physicians in the emergency dept., technicians and physicians in the radiology dept., and technicians and physicians in the nuclear medicine department.

Management must plan for the daily personnel levels. The health-care organizations policies split on duty for 8 consecutive hr. there are cost involved with having too many personnel for a given shift as well as costs involved with not having enough employees to meet unexpected demands. The management objective is to assign human resources to a 1-week schedule that will meet the daily requirements with the minimal payroll costs. The personnel scheduling models have demonstrated that the use of flexibility in designing human resource schedules can result in a substantial improvement in manpower utilization. In determining human resource assignment schedules the following assumptions are model(1). The organization operates 24 hrs. a day, (2) all time periods are equal length, (3) every employee performing the same type of work will received exactly the same salary, and (4) extraordinary overlap does not exists.

Subjective decision that are based on past experience and institution are very common in assigning personnel to several jobs mathematical programming can help verify the results arrived at by subjective decision making and indicate errors involve in the selection of an optimal course of action.

Table 1. Available Human Resources in Each Department

Total Level	Available Requirement		
	Emergency (j=1)	Radiology (j=2)	Nuclear Med. (j=3)
Physician	8	15	12
Nurse	30	-	-
Technician	-	65	24
Total	38	80	36
Target ratio of nurse/physician	3.5	-	-
Target ratio of Tech/physician	-	3.5	3.5
Proportion to stay in j from t to t+1	50%	50%	50%

Table 2. Annual Salary of each human resource

Annual Salary		
Physician	Nurse	Technician
Rs. 70,000	Rs.33,000	Rs. 27,000

The total annual budget (B_T) is Rs. 56,33,000.

Table 3. Initial Target level of Personnel scheduling

Time Period (Shifts)	Available Personnel (Persons)					
	Emergency		Radiology		Nuclear Med.	
	Nurse	Physician	Tech.	Physician	Tech.	Physician
7am-11am	4	1	19	6	7	3
11am-3pm	5	1	19	8	7	3
3pm-7pm	6	2	9	1	7	3
7pm-11pm	6	2	7	0	1	1
11pm-3am	5	1	5	0	1	1
3am-7am	4	1	6	0	1	1

GOAL PROGRAMMING FORMULATION:

The complete Goal Programming formulation based on above data is given as follows:

Minimize: Z =

$$\sum_{j=1}^{3}\sum_{t=1}^{6}[P_1(d_1^+)+P_2(d_2^- + d_2^+)+P_3(d_3^- + d_3^+)+P_4(d_4^- + d_4^+)+P_5(d_5^- + d_5^+)]$$

Subject to System Constraints

Budget Allocation:

$70X_{11}+33Y_{11}+70X_{21}+27Z_{21}+70X_{31}+27Z_{31}+70X_{12}+33Y_{12}+70X_{22}+27Z_{22}+70X_{32}+27Z_{32}+70X_{13}+33Y_{13}+70X_{23}+27Z_{23}+70X_{33}+27Z_{33}+70X_{14}+33Y_{14}+70X_{24}+27Z_{24}+70X_{34}+27Z_{34}+70X_{15}+33Y_{15}+70X_{25}+27Z_{25}+70X_{35}+27Z_{35}+70X_{16}+33Y_{16}+70X_{26}+27Z_{26}+70X_{36}+27Z_{36} = 5633$.-- [1]

Nurse Utilization:

$Y_{12} - 0.5Y_{11} + Y_{13} - 0.5Y_{12} + Y_{14} - 0.5Y_{13} - 0.5Y_{14} + Y_{16} - 0.5Y_{15} \geq 0$ ------------- [2]

Technician Utilization:

Z_{22}-0.5Z_{21}+ Z_{23}-0.5Z_{22}+ Z_{24}-0.5Z_{23}+ Z_{25}-0.5Z_{24}+ Z_{26}-0.5Z_{25}+ Z_{32}-0.5Z_{31}+ Z_{33}-0.5Z_{32}+ Z_{34}-0.5Z_{33}+ Z_{35}-0.5Z_{34}+Z_{36}-0.5$Z_{35} \geq 0$ -- [3]

Physician Flow in Emergency Department (j=1) in period, t=1,………..6:

$$\bar{X}_{11} - X^{0}_{10} - X_{11} - \bar{X}_{12} - - X^{0}_{11} X_{11} - X_{12} + \bar{X}_{13} - X^{0}_{12} X_{12} - X_{13} +$$

$$\bar{X}_{14} - X^{0}_{13} X_{13} - X_{14} - \bar{X}_{15} - - X^{0}_{14} X_{14} - X_{15} + \bar{X}_{16} - X^{0}_{15} X_{15} - X_{16} = 0 - - - - - - - - [4]$$

Physician Flow in Radiology dept. (j=2) in period t=1…….6:

$$\bar{X}_{21} - X^{0}_{20} - X_{21} - \bar{X}_{22} - - X^{0}_{21} X_{21} - X_{22} + \bar{X}_{23} - X^{0}_{22} X_{22} - X_{23} +$$

$$\bar{X}_{24} - X^{0}_{23} X_{23} - X_{24} - \bar{X}_{25} - - X^{0}_{24} X_{24} - X_{25} + \bar{X}_{26} - X^{0}_{25} X_{25} - X_{26} = 0 - - - - - - - - [5]$$

Physician flow in Nuclear medicine Dept. (j=3) in period t=1,……..6:

$$\bar{X}_{31} - X^{O}_{30} - X_{31} - \bar{X}_{32} - - X^{O}_{31} X_{31} - X_{32} + \bar{X}_{33} - X^{O}_{32} X_{32} - X_{33} +$$

$$\bar{X}_{34} - X^{O}_{33} X_{33} - X_{34} - \bar{X}_{35} - - X^{O}_{34} X_{34} - X_{35} + \bar{X}_{36} - X^{0}_{35} X_{35} - X_{36} = 0 - - - - - - - - [6]$$

Upper Limit of Physician Who enter to work in Emergency Dept. (j=2) in period t=1,……..6:

$$\hat{X}_{11} - X_{11} + \hat{X}_{12} - X_{12} + \hat{X}_{13} - X_{13} + \hat{X}_{14} - X_{14} + \hat{X}_{15} - X_{15} + \hat{X}_{16} - X_{16} \leq 0 \text{------------ [7]}$$

Upper Limit of Physician Who enter to work in Radiology Dept. (j=2) in period t=1,……..6:

$$\hat{X}_{21} - X_{21} + \hat{X}_{22} - X_{22} + \hat{X}_{23} - X_{23} + \hat{X}_{24} - X_{24} + \hat{X}_{25} - X_{25} + \hat{X}_{26} - X_{26} \leq 0 \text{---------} [8]$$

Upper Limit of Physician Who enter to work in Nuclear Med. Dept. (j=2) in period t=1,……..6:

$$\hat{X}_{31} - X_{31} + \hat{X}_{32} - X_{32} + \hat{X}_{33} - X_{33} + \hat{X}_{34} - X_{34} + \hat{X}_{35} - X_{35} + \hat{X}_{36} - X_{36} \leq 0 \text{----------} [9]$$

Goal Constraints

Minimum Payroll Goal (Priority1):

$$\begin{aligned}
&70X_{11} + 33Y_{11} + 70X_{21} + 27Z_{21} + 70X_{31} + 27Z_{31} + 70X_{12} + 33Y_{12} + 70X_{22} + 27Z_{22} + \\
&70X_{32} + 27Z_{32} + 70X_{13} + 33Y_{13} + 70X_{23} + 27Z_{23} + 70X_{33} + 27Z_{33} + 70X_{14} + 33Y_{14} + \\
&70X_{24} + 27Z_{24} + 70X_{34} + 27Z_{34} + 70X_{15} + 33Y_{15} + 70X_{25} + 27Z_{25} + 70X_{35} + 27Z_{35} + \\
&70X_{16} + 33Y_{16} + 70X_{26} + 27Z_{26} + 70X_{36} + 27Z_{36} + d_1^{+} = 0 ----------------[10]
\end{aligned}$$

Physician Utilization Goal (Priority 2):

$$\begin{aligned}
&Z_{21} - 3.5X_{21} + Z_{22} - 3.5X_{22} + Z_{23} - 3.5X_{23} + Z_{24} - 3.5X_{24} + Z_{25} - 3.5X_{25} + \\
&Z_{26} - 3.5X_{26} + Z_{31} - 3.5X_{31} + Z_{32} - 3.5X_{32} + Z_{33} - 3.5X_{33} + Z_{34} - 3.5X_{34} + \\
&Z_{35} - 3.5X_{35} + Z_{36} - 3.5X_{36} + d_2^{-} - d_2^{+} = 0 ------------------------[11]
\end{aligned}$$

Physician Assignment Goal (Priority 3):

$$\begin{aligned}
&X_{11} + X_{12} + X_{13} + 2X_{14} + X_{15} + X_{16} + 6X_{21} + 8X_{22} + X_{23} + 3X_{31} + 3X_{32} + 3X_{33} + \\
&X_{34} + X_{35} + X_{36} + d_3^{-} - d_3^{+} = 0 ------------------------------[12]
\end{aligned}$$

Nurse Utilization Goal (Priority 4):

$$Y_{11} - 3.5X_{11} + Y_{12} - 3.5X_{12} + Y_{13} - 3.5X_{13} + Y_{14} - 3.5X_{14} + Y_{15} - 3.5X_{15} + Y_{16} - 3.5X_{16} + d_4^- - d_4^+ = 0 ---------------------------------[13]$$

Technician Utilization Goal (Priority 5):

$$X_{11} + 1.5X_{12} + 2.75X_{13} + 3.375X_{14} + 2.688X_{15} + 2.344X_{16} + 6X_{21} + 11X_{22} + 6.5X_{23} + 3X_{31} + 4.5X_{32} + 5.25X_{33} + 3.625X_{34} + 2.813X_{35} + 2.406X_{36} + d_5^- - d_5^+ = 42 ----[14]$$

RESULT AND DISCUSSION

The model was solved by using QM for Windows. The solution of personnel scheduling for the emergency department, radiology department, and nuclear medicine department is found at the 42nd iteration.

Table 4. Analysis of the Objective Function

Deviational Variable		Goal Priority	Goal Achievement
$d_1^+ (= 0)$	$d_1^- (= 210.000)$	P_1=0.0000	Fully Achieved
$d_2^+ (= 0)$	$d_2^- (= 0)$	P_2=0.0000	Fully Achieved
$d_3^+ (= 2.210)$	$d_3^- (= 0)$	P_1=2.210	Partially Achieved
$d_4^+ (= 0)$	$d_4^- (= 139.250)$	P_2=139.250	Partially Achieved
$d_1^+ (= 35.150)$	$d_5^- (= 0)$	P_1=35.150	Partially Achieved

Table 5. Analysis of Decision Variables

Time Period (Shifts)	Available Personnel (Persons)					
	Emergency		Radiology		Nuclear Med.	
	Nurse (Y1)	Physician (X1)	Tech. (Z2)	Physician (X2)	Tech. (Z3)	Physician (X3)
7am-11am	4	1	19	6	7	3
11am-3pm	8	1	20	8	6	3
3pm-7pm	5	2	11	1	4	3
7pm-11pm	4	2	6	0	3	1
11pm-3am	4	1	4	0	3	1
3am-7am	5	1	5	0	1	1

As shown in Table 4, the first two goals (P1=0.000 in d_1^+ and P2=0.000 in both d_2^- and d_2^+) are satisfied and all other goals are not satisfied. The negative deviational variable d_1^-=210.000 means that there is a savings of Rs. 2,10,000 in the new personnel scheduling established by this GP model.

Table 5 shows the decision variables with their values. The solution for personnel assignment (nurses, doctors, and technologists) in each department (emergency, radiology and nuclear medicine) suggests optimal results. The original solution has fractional values in nurse and technicians scheduling, because they are the proportional values to physicians. Except the radiology department where no physician is on duty in all three department. In reality, health-care organizations manage this type of situations by using an on-call system even though it is not necessary to have certain kinds of personnel in attendance during all hours of operation.

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