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نموذج تخصيص الموارد في مؤسسة خدمات الرعاية الصحية الطارئة باستخدام برمجة الهدف

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الخلاصة

واحدة من القضايا الرئيسية التي تكون من هواجس المدراء في المنظمات العديدة هي توفير الموارد اللازمة لرفع امكانات النظام رغم القيود المالية والميزانية. من الحالات الهامة هي إدارة تخصيص الموارد في مؤسسة خدمات الرعاية الصحية الطارئة. إنّ هذه الدراسة تقدم نظرة كافية في العلاقة بين تخصيص الموارد (البشرية وتسهيلات ومعدات المستشفى) على مراكز الطوارئ فيما يتعلق بالقيود المفروضة على اهداف عديدة (تشمل التكلفة، وعدد من المرضى المقبولين، الدورة الزمنية، وقدرة على الخدمة، الخ...). ان هذه المشكلة يتم صياغتها كنموذج متعدد الأغراض بواسطة البرمجة الخطية. يستخدم عملية التحليل الهرمي (AHP) كأداة من أدوات اتخاذ القرار متعدد المعايير لحصول على وزن الأهداف. لذلك قمنا بدراسة وتحليل إحدى من مؤسسات الطوارئ بناء على الاستبيانات. وبالمقارنة مع الوضع الحالي، تم تحقيق 12,7% من الأهداف. وأخيرا، تم فحص سلوك النموذج في ظل سيناريوهات مختلفة ويتم عرض ومناقشة النتائج الحسابية.

A resource allocation model in a healthcare emergency center using goal programming

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ABSTRACT

One of the most important issues, which most managers in many organizations are concerned about is procuring required resources to maximize system capacity in presence of financial budget restrictions. Management of resource allocation in emergency healthcare centers is a significant area in this case. This study provides an insight into resource (personnel and hospital equipment and facilities) allocation problem for emergency healthcare centers considering different constraints along with multiple goals (including cost, number of admitted patients, cycle time, service capacity, etc.). The problem is formulated as a multi-objective mixed integer linear programming model and it is solved by a weighted goal programming method. The AHP method is used to achieve the weight of goals. A case study with practical data collected from a healthcare center is presented to show the applicability of the proposed model. According to a comparison with the current state, 12.7% improvement in achieving goals is realized. Finally, the behavior of the model is investigated under different scenarios and computational results are presented and discussed.

Keywords: AHP; emergency healthcare center; goal programming; mathematical programming; resource allocation.

INTRODUCTION

Emergency centers are medical treatment departments that prepare healthcare services for patients without any prior appointments. Therefore, there is not any precise and accurate information about the daily number of patients. There are some internal and external factors (e.g. distance, social and psychological factors, the economic and demographical features and availability of other nearby emergency centers) that can affect customers (patients) to choose an emergency center to receive healthcare services. In this study, internal factors are considered to improve the efficiency of whole emergency system (Béland *et al.,* 1998). In fact, a useful vision for decision makers who deal with management of internal factors is prepared to maximize the efficiency of emergency center.

Emergency centers, like other agencies preparing specific services to their customers, need trained human resources and equipment to have expected function. In fact, these are system's resources, which can be grouped as internal factors and decision makers have the authority to make different choices about them in order to promote system's services.

This study concentrates on resource allocation in an emergency center in presence of different restrictions, which exist in any real world problem. Resource allocation is the process of dividing available resources to several competing objectives in order to achieve a satisfactory level of all goals. Due to the conflicting and inconsistent nature of objectives, the method which is applied for resource allocation can considerably affect the efficiency of whole resources. In this paper, the resource allocation problem is presented as a multi-criteria mathematical programming model and a weighted goal programming method is utilized to deal with the conflicting objectives (i.e. minimization of cost and maximizing the number of admitted patients or minimizing the patient's cycle time, etc.) in the problem. According to variations in different decision makers' opinion and different policies of healthcare centers, it seems that this method, through different weighting, provides more suitable flexibility in classifying and prioritizing goals rather than other goal programming methods such as preemptive goal programming method.

LITERATURE REVIEW

One of the most important problems, which all decision makers in organizations are concerned about is resource allocation. All companies need to apply specific methods to allocate available and limited resources in order to reduce their operational costs, which is an essential factor in company economic survival (Gonzalez *et al.,* 2002).

Resource allocation problems can be classified in microeconomics topics or in some other related fields like welfare economics. One of the most important areas in which resource allocation problems are applied is emergency centers management. Kwak & Lee (1997) proposed a linear programming model for planning and allocation of human resources in a healthcare organization. This model aims at minimizing total payroll costs of human resources by allocating them to the appropriate shift hours, considering a satisfaction level for patients. They applied a preemptive goal programming method to solve the model, using data obtained from a healthcare organization.

Ozkarahan (2000) developed a preemptive goal programming model for planning and allocation of surgeries to the operating rooms in a hospital. The proposed model prioritizes the planned surgeries in each day considering some factors (including rooms functions, surgeon preferences, etc.) in order to meet patients' and physicians' expectations and in addition to increase system efficiency by minimizing idle times and overtimes. Harper (2002) developed a generic framework for modeling hospital resources considering real world conditions. The innovative and new aspect of this framework, in comparison with the previous capacity planning methods, is the application of patient classification techniques. In another study, Bruin *et al.* (2007) applied queuing theory for analyzing bottlenecks in the emergency care chain of cardiac in-patient flow. They aimed at allocating resources (hospital beds) considering maximum allowable number of rejected patients as well as investigating the relationship between changes in customers (patients) arrivals and length of stay (number of days in hospital for a patient) and occupancy rates.

Oddoye *et al.* (2009) presented a simulation model for healthcare planning in a medical assessment unit of a general hospital in UK. They employed a simulation model to offer and evaluate various scenarios in order to achieve optimal clinical workflow. Then a weighted goal programming model is developed in order to challenge the findings from the simulation.

Beaulieu *et al.* (2012) proposed a four steps method to deal with operating rooms scheduling problem, which minimizes cancellations and overtimes and maximizes resources efficiencies with uncertainty. Hulshof *et al.* (2013) developed a mixed integer linear programming model for tactical resource allocation and elective patient admission planning, considering multiple resources, multiple time horizons and several patients with different treatment processes. In fact, this model allocates required resources to several care processes and provides a useful tool to make decisions for patients' treatment plans. Güler *et al.* (2013) improved a weighted goal programming model for scheduling the shifts of the residents in the Anesthesia and Reanimation Department of Bezmialem Vakif University Medical School. They showed that the proposed model has afforded extensive improvements in planning more efficient schedules. In a recent study, Ekin *et al.* (2015) developed a resource re-allocation model with fuzzy constraints in which several risk preference levels are considered. U.S. Army hospital data was used in order to demonstrate effectiveness of the developed model. Turgay & Taskın (2015) presented a fuzzy goal programming, which is concerned about human resources and budget allocation for healthcare organizations in different planning horizons with several types of services. A case study is considered using data obtained from a healthcare organization in Turkey. Li *et al.* (2015) proposed an integer linear programming model, which considers multiple goals such as minimizing the number of patients waiting for service and maximum number of patients in recovery rooms. In terms of medical resource allocation, Feng *et al.* (2015) proposed a multi-objective stochastic resource allocation model for emergency departments. They developed an algorithm to optimize the objective functions simultaneously.

Taking into account all previous studies, we can realize that different aspects of resource allocation for healthcare organizations have been studied. Even though, as far as our knowledge goes, there is no comprehensive model considering all problematic issues of real world situation. For instance, different patients should be prioritized according to the emergency level of situation, which they have, in order to receive treatment and occupy vacancies in healthcare centers. In this study several similar assumptions and factors along with multiple goals have been included in a case study framework for one of the healthcare centers in Iran and real experimental data is used, which provides a useful tool for mangers who deal with time laboring problem of resource allocation.

PROBLEM DEFINITION

A goal programming model is developed for the resource allocation in a healthcare emergency center, which consists of four primary goals as follow:

- Goal 1: Minimize of the total daily costs of resources (personnel and equipment)
- Goal 2: Maximize of total number of admitted patients due to an importance factor
- Goal 3: Minimize total distance travelled by non-admitted patients to the nearest other healthcare centers.
- Goal 4: Minimize the cycle time of patients in the system (emergency center).

All resources are classified into two main categories: human and equipment. Human resources include physicians, nurses and medical assistants. The equipment resources include hospital equipment and facilities such as ECG, Ventilator, Sonography, Spirometery, Radiography and hospital beds.

The first goal concerns the costs. It is assumed that all resources have daily variable costs, which include maintenance and usage costs for equipment and payments for personnel working in the center. These costs have linear relationship with the number of resources, which are allocated. In addition, fixed costs are prorated over variable resource allocation costs by dividing initial cost of equipment by years of its working life and adding annual maintenance costs; then it is divided by 365 (number of days in a year) to obtain daily cost. In the same way, human resources, monthly salaries and wages are prorated over 30 days.

The second goal insures that the patients with different treatments are admitted in emergency center so that the total number of admitted patients is maximized due to an importance factor. First, all kinds of treatments receive a weighted value s_i ($0 \le s_i \le 100$) according to their equipment requirements and then the total amount of weighted values is maximized.

The third goal concerns about the minimization of total distance, which non-admitted patients should travel to reach other healthcare centers, when denied care at this emergency center. It is assumed that the emergency center is planned to provide healthcare services for all people, who are living in a specific region of the city. In other words, all these people first apply for admission in this emergency center and if they are rejected then they will travel a distance to reach to another emergency center. In fact, this goal minimizes the distance traveled by patients who are denied care. It should be noted that, all such patients receive correct directions to the nearest emergency center that can accept them.

Finally the fourth goal minimizes the time that the patients spend in emergency center and includes time of actual healthcare and waiting times. It is worth noting that resources availability can affect this goal dramatically. In other words, the more the number of resources (personnel and equipment) the shorter the service time becomes. Moreover, in order to have a more realistic model and therefore more logical feasible solutions, some secondary goals are considered in the model. The model tries to minimize the difference between the resources specific service capacity and the patients' average arrival rate. Besides, some logical relationships are assumed for the number of resources in the model in such a way that the number of some resources should be determined commensurate with the number of some other ones. These logical relationships make some new requirements (secondary goals) to the model. It is assumed that any resource has a specific service capacity and its deviation from patient's average arrival rate is minimized in the proposed model. Moreover a logical relationship is assumed for the number of resources in the model in such a way that the number of some resources should be determined based on the number of some other resources. These logical relationships make some new requirements to the model and could be considered as secondary goals. Secondary goals are not the main purposes of the model, but are necessary to achieve feasible and logical solutions. Secondary goals of the model are as follow:

- Minimization of the difference between physician's appointment capacity and patient's average arrival rate,
- Minimization of the difference between equipment and patient's average arrival rate,
- Decreasing the difference between the number of nurses and the desired number of nurses according to the number of physicians,
- Decreasing the difference between the number of nurses and the desired number of nurses according to the number of hospital beds,
- Decreasing the difference between the number of medical assistants and the desired number of medical assistants according to the number of hospital beds.

In fact the developed model is a multi-objective model with four primary goals to deal with resource allocation problem in an emergency center, in addition to some other secondary goals to make it more realistic and logical.

Before presenting the model, in order to simplify it to be capable of being solved using linear goal programming methods, all parameters and values in the model are assumed to be deterministic. These kinds of problems have probabilistic natures. Therefore, interval estimation is inappropriate for this study and all parameters are estimated using point estimation. Although in real world problems, total cost has a nonlinear relationship with number of resources, but in this study a linear relationship is assumed to make it possible to be presented as a linear constraint.

THE MATHEMATICAL MODEL

In this section we introduce a mathematical resource allocating model of an emergency center that considers different constraints and objectives of conflicting natures and different priority levels for decision makers. Weighted Goal programming method can be a useful method to deal with this problem. In addition, paired comparison method is applied for taking into account different experts' opinions and determining appropriate weighted values for objectives. In other words, main objective function is a weighted linear combination of goals.

Indices:

i	Index for type of illnesses ($i = 1,...,I$, where I is the number of illnesses types)
r	Index for resources of type ($r \in (R_1 \cup R_2)$, where $R_1 = \{p, n, a, b\}$ is a set of *physician* (p), *nurse* (n), *medical assistant* (a) and *bed* (b); and $R_2 = \{1,...,K\}$, where K is the number of resources of type *equipment*)
z	Index for goals ($z = 1,...,Z$ where Z is the number of goals)

Parameters and variables:

w_z	Weighted value associated with goal z
c_r	Daily usage cost for resource r
$c^{\max}$	Daily maximum cost of resources
s_i	Importance factor for patients with illness i
l_i	Distance to the nearest healthcare center with enough resources to accept the patient i
p^{Ave}	Daily average number of patients
r_i	Percentage of patients with illness i
o_i	Average time (hours) that a patient with illness i needs a hospital bed

a_{ir}	Refers to the entry of row *i* and column *j* of the matrix of required equipment for each type of illnesses
r^{pn}	Ratio of the number of nurses to the number of physicians
r^{bn}	Ratio of the number of nurses to the number of beds
r^{ba}	Ratio of the number of medical assistants to the number of beds
n_r	Daily capacity for resource *r*
U_z	Upper bound of deviation variables of goal *z*
e_i	=1 If patient with illness *i* is admitted; 0 otherwise
x_r	Number of resource *r*
d_z^+	Positive deviation variable for goal *z*
d_z^-	Negative deviation variable for goal *z*

Now the problem is formulated as follows:

$$\min w_1 \frac{d_1^+}{U_1} + w_2 \frac{d_2^-}{U_2} + w_3 \frac{d_3^+}{U_3} + w_4 \frac{d_4^+}{U_4} + \sum_{z=5}^{Z} w_z \frac{d_z^-}{U_z}. \tag{1}$$

s.t.

$$\sum_{r \in (R_1 \cup R_2)} c_r x_r - d_1^+ + d_1^- = c^{\max}, \tag{2}$$

$$\sum_{i=1}^{I} s_i e_i - d_2^+ + d_2^- = 100, \tag{3}$$

$$\sum_{i=1}^{I} l_i (1 - e_i) - d_3^+ + d_3^- = 0, \tag{4}$$

$$\sum_{i=1}^{I} r_i o_i p^{\text{Ave}} e_i - d_4^+ + d_4^- = n_b x_b, \tag{5}$$

$$n_p x_p - d_5^+ + d_5^- = p^{\text{Ave}}, \tag{6}$$

$$n_r x_r - d_{r+5}^+ + d_{r+5}^- = \sum_{i=1}^{I} a_{ir} r_i p^{\text{Ave}} e_i, r \in R_2, \tag{7}$$

$$r^{pn} x_p \le x_n, \tag{8}$$

$$r^{bn} x_b \le x_n, \tag{9}$$

$$r^{ba} x_b \le x_a, \tag{10}$$

$$x_r \geq a_{ir} e_i, i = 1,...,I \ \& r \in R_2, \tag{11}$$

$$x_r \geq 0, r \in R_2, \tag{12}$$

$$x_r \geq 1, r \in R_1, \tag{13}$$

$$e_i \in \{0,1\}, i = 1,...,I, \tag{14}$$

$$d_z^+, d_z^- \geq 0, z = 1,...,Z, \tag{15}$$

$$x_r : \text{int}, r \in (R_1 \cup R_2). \tag{16}$$

Equation (1) is the objective function that minimizes the weighted average of deviation variables. d_z^+ and $d_z^-(z = 1,...,4)$ are deviation variables of the four primary goals and d_z^+ and d_z^- $(z = 5,...,Z)$ are deviation variables of secondary goals. In order to tackle the commensurability of goals, deviation variables are normalized through their upper bounds (U_z). Equation (2) is concerned about resource allocation costs and requires the total resource cost does not exceed $c^{\max}$. Equation (3) is the second objective and aims at maximizing the total admitted patient's importance factor. In an ideal situation, total importance factor is 100 and all patients with any kind of illnesses are accepted by emergency center. Equation (4) presents the third objective, which minimizes the distance which non-admitted patient *i* should travel to reach the nearest other healthcare center with enough resources to receive healthcare services. This objective function will be equal to zero where all patients are accepted with the healthcare center. Equation (5) requires the number of hospital beds not to be smaller than the number which is needed. Equation (6) is concerned about the total capacity of physicians for visiting patients, which should not be smaller than daily average number of patients. Equation (7) makes similar requirements for other resources of type *equipment*. In fact, Equations (5, 6 and 7) refer to the fourth objective. Equations (8, 9 and 10) adjust the number of nurses, medical assistants and hospital beds according to the specific ratios, respectively. r^{pn} is the nurse to physician ratio and requires the number of nurses not to be smaller than the required number. In a similar way, r^{bn} and r^{ba} are the nurse to hospital bed ratio and medical assistant to hospital bed ratio, respectively. It is assumed that patients with different types of illnesses can receive healthcare services in this center and these different types of illnesses need different resources (equipment). Equation (11) insures that a patient with a special illness will be admitted if all required equipment are allocated to the emergency center (e.g., if illness *i* requires equipment Ventilator, Radiography and Spirometery, a patient with illness *i* will be rejected unless all the required equipment are allocated). In other words, variable e_i receives 0 unless all variables related to required equipment are equal to 1). Equations (12) and (13) show the minimum number of resources. It is required that the number of personnel resources and hospital beds not to be smaller than one and requires the number of equipment not to be smaller than zero. In fact, Equation (11) guarantees the minimum number of equipment, therefore, Equation (12) is redundant and can be removed.

MODEL IMPLEMENTATION IN A CASE STUDY

A case study along with related computational studies are presented in order to evaluate the performance of the developed model. All data are collected from Ekbatan Hospital (located in Hamedan, Iran) in 2009. Illnesses (conditions) in this emergency center are divided into 8 categories. These categories and the equipment required for each category are shown in Table 1. Table 2 expresses the distances and capability matrix of nearby healthcare facilities.

Table 1. Required equipment for each type of condition

Condition	Equipment Required				
	ECG	Ventilator	Sonography	Spirometery	Radiography
Pulmonary	0	1	0	1	1
Burns	1	1	0	0	0
Outpatient	0	0	0	0	0
Poisoning	1	1	0	0	0
Stroke	1	1	0	0	1
Cardiac arrest	1	1	0	0	0
Brain hemorrhage	1	1	1	0	1
Fractures	0	1	1	0	1

Table 2. Distance and capability matrix of nearby healthcare facilities

Nearby Healthcare Centers	Distance (km)	Capability of Nearby Healthcare Centers							
		Pulmonary	Burns	Outpatient	Poisoning	Stroke	Cardiac arrest	Brain hemorrhage	Fractures
Kashani	1.7	-	-	1	1	1	1	-	1
Bou Ali	2.1	-	1	1	1	1	1	-	1
Emam	1.9	1	1	1	-	1	1	1	-
Atiyeh	3.2	-	1	1	1	-	1	-	-
Sina	2.0	-	-	1	1	-	-	1	-
Besat	2.2	1	1	1	1	1	1	-	1

Table 3 also presents different conditions importance factors and average number of hours which patients need hospital beds.

Table 3. s_i and o_i for illness (condition) i (number of samples = 50)

Condition	Average time and standard deviation of patients with condition i needs hospital bed		Importance factor for patients with condition i (s_i)
	Average time (hrs) (o_i)	Standard Deviation	
Pulmonary	6	2.47	15
Burns	3	1.14	10
Outpatient	1	0.4	25
Poisoning	4	1.08	10
Stroke	2	0.74	12
Cardiac arrest	3	1.1	18
Brain hemorrhage	2	0.81	4
Fractures	3	0.98	6

According to different priorities of objectives due to their importance for decision makers, it is necessary to determine appropriate weighted values for them. Paired comparison method, which is grouped as analytic hierarchy process (AHP), is applied in order to deal with this problem. AHP is one of the multi-criteria decision making methods, which was first introduced by Thomas L. Saaty in the 1970s and has been developed and applied by many other researchers since then (Saaty, 1980). AHP is a method for prioritizing several goals, taking into account different managers opinions. The first step is to make paired comparison matrix for any expert which presents the paired comparison ratios for all goals according to the priories of each expert. Matrix A shows paired comparison values for expert A where a_{ij} and $1/a_{ij}$ are paired comparison ratios for goals i and j.

$$A = \begin{bmatrix} 1 & \cdots & 1/a_{ij} & \cdots \\ \vdots & \ddots & & \vdots \\ a_{ij} & & 1 & \vdots \\ \vdots & \cdots & \cdots & 1 \end{bmatrix}$$

Tables 4 is a sample of paired comparison matrixes for four primary objectives prepared by an expert (physician).

Table 4. Paired comparison matrix for goals according to the first expert's choice

	1	2	3	4
1	-	1	0.75	0.5
2	1	-	0.75	0.4
3	1.33	1.33	-	0.6
4	2	2.5	1.66	-

Then it is needed to consider all experts' choices simultaneously and obtain the overall paired comparison matrix:

$$T = \begin{bmatrix} 1 & \cdots & 1/b_{ij} & \cdots \\ \vdots & \ddots & & \vdots \\ b_{ij} & & 1 & \vdots \\ \vdots & \cdots & \cdots & 1 \end{bmatrix},$$

where b_{ij} is calculated as:

$$b_{ij} = \left(\prod_{k=1}^{N} a_{ij}^{(k)}\right)^{1/N},$$

where index k refers to the paired comparison matrix associated with expert k and N is the number of goals. Table 5 shows the overall paired comparison matrix which is obtained from three expert's paired comparison matrix.

Table 5. Overall paired comparison matrix for goals

	1	2	3	4
1	-	1.66	0.75	0.466
2	0.867	-	0.616	0.366
3	1.337	1.666	-	0.533
4	2.166	2.777	1.888	-

Finally weighted least square technique is applied to determine weighted values for goals. Obtained weighted values for goals are as: W = (0.19, 0.16, 0.25, 0.40). It should be noted that, experts make their choices independently. Moreover, consistency ratio for paired comparison matrix is equal to 0.988 which is acceptable. In addition, decision makers can assign different weighted values according to their choices. In some cases, emergency center is like a private-sector organization and decision makers aim at minimizing resources usage costs, while in some other cases, emergency center is considered as a non-profit organization and decision makers are concerned about the quality of healthcare services (e.g., patients waiting time for receiving service).

Daily capacities for resources are given in Table 6.

Table 6. Daily capacity for resource *i*

Resource	n_1	n_2	n_3	n_4	n_5	n_p	n_n	n_a	n_b
Daily Capacity	48	48	48	48	48	192	–	–	24

As presented in Table 6, $n_r, r \in R_2$, which refers to daily capacities of equipment are equal to 48 patients. n_p refers to the number of the patients whom a physician can treat every day (in 24 hours). There is no capacity constraint for nurses and medical assistants (shortage is not applicable to them). Also n_b shows a hospital bed capacity for one day which is equal to 24; which is trivial, each bed can receive only one patient in any one hour time interval. Suppose that daily average number of patients (p^{Ave}) is equal to 1000. Finally, Table 7 shows the percentages of people with different types of condition:

Table 7. The percentage of patients with condition *i*

Condition	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8
Percentage	0.1	0.2	0.15	0.15	0.05	0.05	0.2	0.1

Also the resources daily usage costs, $c_r, r \in (R_1 \cup R_2)$ are as below in Table 8.

Table 8. Daily usage costs for resource *i*

Resource	c_1	c_2	c_3	c_4	c_5	c_p	c_n	c_a	c_b
Daily usage costs	6	8	23	4	9	3	1	1	1

Collected data are used to execute numerical computations on the developed model. Computations are implemented using CPLEX Solver in GAMS 23.5 software. In order to evaluate the performance of the model, different scenarios are designed and the results are presented.

Tables 9 and 10 summarize the comparison of the current state of the emergency center with the suggested results achieved from the model where $c^{\max}$ is 400 and r^{pn}, r^{bn} and r^{ba} are 3, 0.8 and 1, respectively. Table 9 shows the number of resources allocated to the emergency center and Table 10 compares the admitted conditions (considering the cost restriction along with other constraints) in the model with the ones in the current state in the attempted emergency center. It shows that, except brain hemorrhage, all other types of conditions are admitted. Moreover, objective functions achieved from the model shows improvement (12.7%) in comparison with the one attained form current state.

Table 9. Allocated number of resources where $c^{max} = 400$

Resources	ECG x_1	Ventilator x_2	Sonography x_3	Spirometery x_4	Radiography x_5	Physician x_p	Nurse x_n	Medical assistant x_a	Bed x_b
Model	10	13	2	2	5	6	34	42	42
Current state	11	11	3	4	6	7	23	35	28

Table 10. Admitted patients where $c^{max} = 400$

	Conditions								Obj. Func.
	e_1	e_2	e_3	e_4	e_5	e_6	e_7	e_8	
Model	1	1	1	1	1	1	0	1	0.089
Current state	1	1	1	1	1	1	0	1	0.102

Cost analysis

In this section, a brief analysis of model performance for different values of c^{max} is presented. Table 11 summarizes the computational results which indicate some useful points. One of the most important points is the achieved values for objective functions. As it is presented, for $c^{max} = 200$, the value of the objective function is 0.155; but greater amounts of c^{max} result in smaller (better) values for objective function. Finally the best possible value for objective function is achieved where c^{max} is 850. Moreover, regarding to normalized goals and due to proximity of goals weight values, the objective function growth pattern shows almost a linear trend (see Figure 1). Another important feature is the changes in types of admitted conditions. Where $c^{max} = 850$, patients with all types of conditions are admitted; but the smaller the c^{max} the more the number of rejected patients and finally where $c^{max} = 200$, the emergency center does not accept two types of conditions (i.e. conditions 7 and 8).

Table 11. Computational results for different values of c^{max}

c^{max}	x_1	x_2	x_3	x_4	x_5	x_p	x_n	x_a	x_b	e_1	e_2	e_3	e_4	e_5	e_6	e_7	e_8	Obj. Func.	CPU time (s)	Iter.
200	9	10	0	2	3	5	15	1	1	1	1	1	1	1	1	0	0	0.155	0.08	13
250	8	13	1	2	4	5	15	1	1	1	1	1	1	1	1	0	1	0.142	0.05	15
300	10	13	2	3	5	5	16	1	1	1	1	1	1	1	1	0	1	0.119	0.02	12
400	10	13	2	2	5	6	34	42	42	1	1	1	1	1	1	0	1	0.089	0.06	10
500	9	14	2	2	5	6	62	77	77	1	1	1	1	1	1	0	1	0.064	0.08	16
600	10	14	2	3	6	6	84	105	105	1	1	1	1	1	1	0	1	0.041	0.08	17
700	14	18	6	3	10	6	61	77	76	1	1	1	1	1	1	1	1	0.034	0.08	17
800	14	18	6	2	10	6	96	120	120	1	1	1	1	1	1	1	1	0.008	0.06	19
850	14	18	7	3	10	6	97	121	121	1	1	1	1	1	1	1	1	0	0.03	1

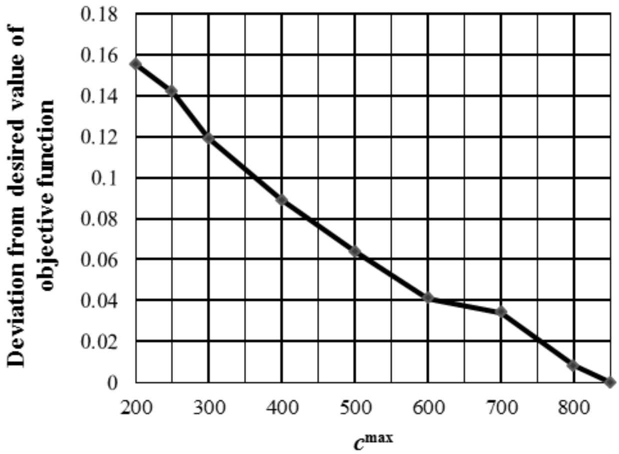

Fig. 1. Objective function cost curve

Sensitivity analysis for daily average number of patients

Developed model consists of different objectives. These objectives are significantly related to the daily average number of patients and variations of this parameter effects on achieving the goals. Therefore, it can be a critical parameter for decision and policy makers to concern about. Table 12 presents an analysis of the model performance for different values of p^{Ave} when c^{max} = 850. Not surprisingly, increasing p^{Ave} will intensify the deviation from the objectives. But it would be interesting that 850 unit of investment (c^{max} = 850) can be up to servicing one and a half times the current value of the daily average number of patients without significant harm to the goals scored (see Figure 2).

Table 12. Total importance factor values

p^{Ave}	e_1	e_2	e_3	e_4	e_5	e_6	e_7	e_8	Obj. Func.
900	1	1	1	1	1	1	1	1	0
1000	1	1	1	1	1	1	1	1	0
1100	1	1	1	1	1	1	1	1	0.014
1200	1	1	1	1	1	1	1	1	0.033
1300	1	1	1	1	1	1	0	1	0.04
1400	1	1	1	1	1	1	0	1	0.04
1500	1	1	1	1	1	1	0	1	0.046

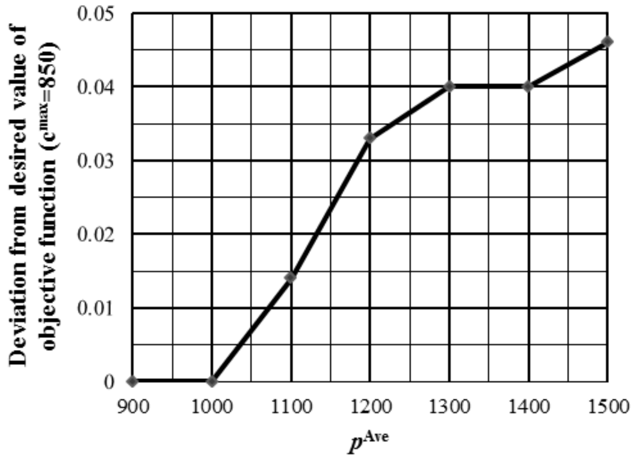

Fig. 2. Daily average number of patients curve

CONCLUSIONS

This study provides a framework for available and limited resources (human and equipment) allocation in an emergency healthcare center. Any organization needs variety of resources to do its functionality and provide products or services to its customers. In addition, there are many other factors (e.g., cost, customers satisfaction, service time, etc.), which should be taken into account. In this paper, a multi-objective linear programming model is developed, which seeks to optimize some primary objectives as well as some secondary ones. Due to the conflicting nature of mentioned objectives, it is necessary to make a trade-off between them to achieve the optimum solution. In order to overcome this problem, goal programming method is applied to solve the model and minimize the gaps between obtained values and determined goals. Numerical computations are implemented using data obtained from a healthcare center, and a comparison was carried out to show the improvement (12.7%) of the proposed model in contrast with the current state. Finally, sensitivity analyses over daily maximum cost of resources (c^{max}) and daily average number of patients (p^{Ave}) were accomplished. The approach applied in this paper can be further extended in future studies to conquer limitations of this research. For example, instead of assuming the parameters and values to be deterministic, it would be interesting to take the uncertainty into account through different approaches. The problem can be also investigated through various strategies and priorities of considering a healthcare emergency center as a profit/non-profit organization. More details can be considered in the model (e.g. physicians are assumed to treat all patients with different types of conditions). In addition, more realistic nonlinear objective functions can be attempted in the future.

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REFERENCES

Beaulieu, I., Gendreau, M. & Soriano, P. 2012. Operating rooms scheduling under uncertainty. In: Tanfani, E. & Testi, A. (Eds). Advanced Decision Making Methods Applied to Health Care. Springer Milan, **173**:13-32.

Béland, F., Lemay, A. & Boucher, M. 1998. Patterns of visits to hospital-based emergency rooms. Social Science & Medicine, **47**(2):165–179.

de Bruin, A.M., Van Rossum, A.C., Visser, M.C. & Koole, G.M. 2007. Modeling the emergency cardiac in-patient flow: an application of queuing theory. Health Care Management Science, **10**(2):125–137.

Ekin, T., Kocadagli, O., Bastian, N.D., Fulton, L.V. & Griffin, P.M. 2015. Fuzzy decision making in health systems: a resource allocation model. EURO Journal on Decision Processes, 1-23.

Feng, Y.Y., Wu, I. Ch. & Chen, T.L. 2015. Stochastic resource allocation in emergency departments with a multi-objective simulation optimization algorithm. Health Care Management Science, 1-21.

Gonzalez, R.M., Langholtz, H.J. & Sopchak, B. 2002. Minimizing cost in resource allocation decisions. Organizational behavior and human decision processes, **89**(2):1032-1057.

Güler, M.G., İdi̇n, K. & Gül, E.Y. 2013. A goal programming model for scheduling residents in an anesthesia and reanimation department. Expert Systems with Applications, **40**(6):2117-2126.

Harper, P.R. 2002. A Framework for Operational Modeling of Hospital Resources. Health Care Management Science, **5**(3):165–173.

Hulshof, P.J., Boucherie, R.J., Hans, E.W. & Hurink, J.L. 2013. Tactical resource allocation and elective patient admission planning in care processes. Health Care Management Science, **16**(2):152–166.

Kwak, N.K. & Lee, Ch. 1997. A linear goal programming model for human resources allocation in a health care organization. Journal of Medical Systems, **21**(3):129-140.

Li, X., Rafaliya, N., Baki, M.F. & Chaouch, B.A. 2015. Scheduling elective surgeries: the trade-off among bed capacity, waiting patients and operating room utilization using goal programming. Health Care Management Science, 1-22.

Oddoye J.P., Jones D.F., Tamiz, M. & Schmid P. 2009. Combining simulation and goal programming for healthcare planning in a medical assessment unit. European Journal of Operational Research, **193**(1):250-261.

Ozkarahan, I. 2000. Allocation of surgeries to operating rooms by goal programming. Journal of Medical Systems, **24**:339-378.

Saaty, T.L. 1980. The analytic hierarchy process, planning, piority setting, resource allocation. McGraw-Hill, New York.

Turgay, S. & Taskın, H. 2015. Fuzzy goal programming for health-care organization. Computers & Industrial Engineering, **86**:14-21.

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