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Robust Estimation in Multi Criteria Operating Room Allocation under Downstream Resources Constraint: a Case Study

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Abstract

This study describes a methodology for multi criteria operating room allocation at the strategic level of hospital planning. Operating room allocation is one of the most important core issue in hospital strategic planning. This problem aims at assigning capacity of operating room (OR) to surgical groups based on characteristics, constrains and objectives of hospitals. In order to obtain an optimal allocation, a linear programming (LP) model is developed different performance measures of the OR are considered. Since the data used to estimate parameters of the developed model is derived from an Iranian medium size hospital, a robust estimation is developed to down weight outlier data. The developed model is solved using GAMS software and a sensitivity analysis is conducted to find the impact of changes in terms of resources on the objective function of the problem.

Keywords:
Operating Room Allocation, Robust Estimation, Multi Criteria, Linear Programming

Introduction

In Iran like most other countries, total health expenditures increase year after year and can expand potentially in the future. Also, as mentioned by WHO reports, a huge portion of the treatment cost is paid by the government. This portion in 2000 was about 37 percent, and in 2012 was more than 40 percent. As the government has a double emphasis on increasing the budget in the field of health, the necessity for proper management in this area is critical. On the other hand, hospitals are the most important sector in healthcare system. So, proper management of healthcare system without considering hospital resources is not logical. In addition, it is estimated that about 60% to 70% of the hospital admissions need OR [1]. So, hospital managers are normally concerned with handling the surgeries through optimizing planning and scheduling of the OR, known as the main part of costs and revenues of the hospitals [2]. As reported by “Healthcare Financial Management Association”, OR results in an estimated 40% of hospital revenue [3]. So, hospital managers shall provide the most effective OR plan and schedule to the citizens using the limited resources. For this purpose, they need effective methods for planning, and scheduling of OR.
Hans et al. [4] introduce a framework of hospital management issues and classified them into strategic, tactical and operational levels, while focusing on four areas of medical planning, resource capacity planning, material planning and financial planning.
The aim of this study is to solve resource capacity planning problem in strategic level of OR planning and scheduling. It includes determining the type and composition of the patient, i.e. case mix planning, over a period of time. As well as for the real-world conditions, constraints are defined and modeled according to Shahid Madani hospital condition. Also, the parameters of developed model have been estimated based on real data derived from Shahid Madani hospital information system (HIS). Usually in statistical analysis, it is supposed that the data required for the problem follows a specific distribution. So, various classical methods such as maximum likelihood estimation (MLE) or method of moment’s estimation can be used to estimate distribution parameters. In this study, the required data is collected from Shahid Madani HIS. So, existence of contamination in the collected data is indisputable. Therefore, a robust estimation approach is developed to estimate the model parameters in a way that they are not sensitive to contaminations and outliers.
Even though OR time allocation is a central issue in the strategic planning of a hospital, this subject has rarely been studied by the researchers in the past. In contrast, this problem has been gaining increased attention in the course of the last three decades [5]. Lots of studies [5, 6, 7] classified the literature of OR planning and scheduling. Cardeon et al. [7] presented a comprehensive classification

of the OR planning and scheduling. In particular they distinguished between 6 fields: 1) patient characteristics, 2) performance measures, 3) decision delineation, 4) research methodology, 5) uncertainty and 6) applicability of research and classified researches base on these fields.
In order to simplify presentation of related studies we use this classification to present related articles. In addition, due to the fact that outlier data effects on the obtained results, using robust estimators is mentioned in our review. Different perspective by each field is as follow:
• Patient type (elective inpatient (1), non-elective inpatient (2), outpatient (3))
• Performance measures (waiting time (1), Throughput (2), Makespan (3), Leveling (4), utilization of resources (5), Patient deferral/refusal (6), financial (7), Preferences (8), emergency waiting time (9), overtime, undertime (10))
• Uncertainty (surgery duration (1), arrival (2), length of the stay (3), demand (4), other(5))
• Decision delineation (date (1), time (2), room (3), capacity (4) and decision on the patient (1) the surgeon (2), surgical group (3))
• Integrity (isolated (1), integrated (2))
• Type of analysis (optimization (1), decision problem (2), benchmarking (3), scenario analysis (4))
• Solution technique (mathematical planning (1), DEA (2), heuristic and meta heuristic algorithm (3), Analytical procedure (4), simulation (5))
• Estimation Method (classical estimation (1), robust estimation (2))
Table 1 depicts studies that consider resource capacity planning in strategic level of OR planning and scheduling.
In our study, according to the governmental nature of Shahid Madani hospital, the most important priority is covering patients who need governmental facility the most. So, a special measure, "value of patient", shall be defined and calculated for each surgical group. The "value of patient" is defined according to patient's group demand and possibility of patients being referred to another hospital. To calculate "value of patient" for each patient's group, a weighted sum method is applied to consider these criteria.
Also, OR planning and scheduling decisions affect downstream resources. Therefore, it seems to be essential to incorporate these resources, such as the ICU or ward beds, in the decision-making process. So in this study to achieve global performance, we try to allocate or time to different surgical groups while OR hours, ICU and surgical ward beds capacity are considered as the most important limitation.

Table 1- Resource capacity planning articles

Author	year	Patient type	Performance measures	Uncertainty	Decision delineation	Integrity	Type of analysis	Solution technique	Estimation Method
Lovejoy & Li [8]	2002	1	1,7	1,2	4-3	1	4	5	1
Kuo et al [9]	2003	1,2,3	7	---	4-3	1	1	1	1
Mulholland et al [10]	2005	1	7	---	4-3	2	1	1	1
Niu et al [11]	2007	1,2	1,5	1,2	4-3	1	4	5	1
VanBerkel & Blake [12]	2007	1,2,3	1,2	1,2	4-3	1	4	5	1
Gupta [13]	2007	1	7	---	4-3	1	1	1	1
Ma et al [14]	2009	1	7	---	4-3	2	1	1,3	1
Ma & Demeulemeester [15]	2013	1	7	---	4-3	2	1	1	1
Heng & Wright [16]	2013	1,2	1,2,5,6,9,10	2	Emergency room count	1	Queuing	4	1
Ferrand et al [17]	2014	1,2	1,5,9,10	1,2	Operating room count	1	4	5	1
Choi & Wilhelm [18]	2014	1,2	6,10	1,4	4-3	1	1	1	1
Yahia et al [19]	2015	1,2	1	1,2,3	4-3	2	1	1	1
This article	2015	1,2,3	1,8	---	4-3	2	1	1	2

Another aspect which is considered in our study is the use of robust estimator to estimate developed model parameters with regarding to existence of contamination in real recorded data. Usually it is assumed that the data are following special distributions. So to estimate parameters of distribution various classical methods like MLE, are applied. In this study, the model parameters are estimated according to real data collected from Shahid Madani HIS. So, to down weight outliers, a new robust estimation is developed to estimate parameters of the model in a way that they are not sensitive to outlier data.
The rest of the paper is organized as follows. Problem definition and the proposed mathematical programming model are presented in section 2. Section 3 represents developed robust estimation. In section 4 results of solving developed model is conducted, while section 5 provides conclusions and potential areas for future studies.

Problem definition and mathematical formulation of the problem

The process of OR planning and scheduling consists of three steps. 1) Resource capacity planning, 2) master surgical scheduling and 3) planning and scheduling patients in operational level. Review of articles shows that there are many performance measures for resource capacity planning in hospitals. They diverse from financial goals to emergency patient waiting time reduction. In Shahid Madani covering patients who have less chance to be operated in other hospitals is considered as one of the most important performance measures, while patient's groups demand take to consideration as an important criteria during resource capacity planning. So the aim of this study is to assign OR capacity to surgical groups in such a way that maximizes value of operated patients while considering real world conditions. The constrained resources used in the linear programming model are number of beds in wards and ICU as downstream resources and number of appropriate operating room for each surgical group. If a patient needs ICU bed after the surgery, and there is not any empty bed in the ICU, the surgery will be canceled. Also only elective patients are considered in this study. Indeed, it is assumed that there is a reserve capacity for the emergency patients. In addition, certain procedures can only be performed in some special OR. Activated OR days for elective surgeries are Saturday to Wednesday each week, from 8 am to 5 pm. Planning horizon is one year and lower limits of patients for each surgical group is determined according to hospital policy.

Here we describe a linear programing model for determining OR time allocation to surgical groups. Table 2 represents variables and parameters required for modeling the problem.

Table 2- Model variables and parameters

Model elements		Definition
Sets	I	The set of surgical groups, indexed by *i*
	R	The set of ORs, indexed by *r*
	C	The set of wards, indexed by *c*
	G	The set of patients sex groups (male, female and Pediatrics), indexed by g
Variables	x_i	OR time which is allocated to surgeon group *i*
	x_{ir}	The time of *r*th OR time allocated to surgical group *i*
	x_{ig}	The time of surgical group *i* that is allocated to patient sex group *g*
	y_{igc}	Portion of operated patients of surgical group *i* which is assigned to ward *c* and are in patient sex group *g*
	p_{igc}	Number of required ward beds of patients sex *g* of surgical group *i* that is supported by wards except ward *c*
	Cap_i	The OR time allocated to surgical group *i* in the past year
	h_r	Opening hours of OR *r*
Parameters	DY_i	Demand of elective patients group *i* in the year
	R_{ir}	If OR *r* is appropriate for the surgical group *i*; is equal to 1; otherwise, 0
	α_i	Maximum decrease rate of surgical group *i* capacity compared with the last year capacity
	w_c	Ward *c* beds capacity
	K_{igc}	If ward *c* is appropriate for the patient sex group *g* of surgical group *i*; is equal to 1; otherwise, 0
	stw_i	Average LOS of surgical group *i* patients in the ward
	stI_i	Average LOS of surgical group *i* patients in the ICU
	T_i	Average surgery time duration of surgical group *i*
	VP_i	"Value of patient" of surgical group *i*

The LP model is then formulated as follows:

$$\sum_i x_{ir} \le h_r \qquad \forall r \qquad (1)$$

$$\sum_r x_{ir} = x_i \qquad \forall i \qquad (2)$$

$$x_{ir} \le h_r.R_{ir} \qquad \forall i,r \qquad (3)$$

$$\sum_{i\neq burn} \frac{x_i}{T_i} \times stI_i \le w_9 \qquad \forall i \qquad (4)$$

$$\frac{x_i}{T_i} \times stI_i \le w_{10} \qquad i\text{=burn} \qquad (5)$$

$$\sum_i \sum_g k_{igc} \times \frac{x_{ig}}{T_i} \times stw_i \times y_{igc} \le w_c \qquad \forall c \qquad (6)$$

$$x_i \ge (1-\alpha_i)Cap_i \qquad \forall i \qquad (7)$$

$$x_i \le DY_i.T_i \qquad \forall i \qquad (8)$$

Equation (1) ensures that the time allocated to a surgical group does not exceed available time of OR, while Equation (2) shows the total allocated time of each surgical group. Equation (3) guaranties that each surgery can be carried out in an inappropriate OR. After a surgery, all patients are moved to the general or burned ICU if necessary. Constraints (4) and (5) are related to the capacity constraints of general and burn ICU beds, respectively. In Equations (4) and (5), w_9 and w_{10} represent bed capacity of general and burn ICU, respectively. The balance between allocated capacity of OR to surgical groups and hospital wards capacity is a challenging issue. Constrain 6 ensures that total LOS of surgical groups do not exceed their corresponding ward capacity. In Equation (6) y_{igc} is a positive variable that determine the portion of operated patients of surgical group *i* which is assigned to ward *c*. Indeed, patients of a special surgical group can stay in different wards in the hospital.

Note that $0 \le y_{igc} \le 1$ and $\sum_C y_{igc} = 1$. Equation (6) shall be amended as Equation (9) since it is a nonlinear equation.

$$\sum_i \sum_g k_{igc} \times \frac{x_{ig}}{T_i} \times stw_i - p_{igc} \le w_c \qquad \forall c \qquad (9)$$

And:

$$\frac{x_{ig}}{T_i} \times stw_i = \sum_c p_{igc} \qquad \forall i, g \qquad (10)$$

Equations (7) and (8) determine lower and upper limits of the allocated OR time which are assigned to each surgical group. It is assumed that in each surgical group, a minimum amount of OR time shall be allocated based on hospital policy. On the other hand, this policy is based on gradual reduction of capacity for the surgical groups. Finally, it is considered that the allocated time of OR to surgical group *i* should not exceed its maximum time required, i.e. the demand of surgical group *i*.

Objective function

The optimum case mix of operated patients is the mix of most required patients. Identification of most required patients needs to define “value of patient” for each surgical group. According to hospital manager and medical staff interviews, surgical group patients’ demand and possibility to refer surgical group patients to other governmental hospital in Alborz province are the most important factors should be considered when the “value of patient” wants to be calculated. Note that, number of hospital that can cover patients of a special surgical group can be used as a surrogate of possibility to refer surgical group patients to other governmental hospital, hereinafter, is called “referral number”. Indeed, increasing referral number in a special surgical group results in increasing the chance of finding a hospital for the patients of that surgical group. Shahid Madani Surgical groups demand and ability to cover surgeries by other hospitals are summarized in Table 3.
These data derived according to data collected in the period of March 20, 2014 to July 21, 2015.
We propose a two-step procedure to define and compute “value of patient” of surgical groups. In the first step, we normalize the surgical group demand and referral number using Equation (11) and (12). In the second step, we compute the “value of patient” as the weighted sum of two components $VP_i = \alpha D_i + \beta RN_i$; where α and β are positive numbers ($\alpha + \beta = 1$).

$$D_i = \frac{DY_i}{\sum_I DY_i} \qquad \forall i \qquad (11)$$

$$RN_i = \frac{\frac{1}{RN_i}}{\sum_I \frac{1}{RN_i}} \qquad \forall i \qquad (12)$$

So, the objective function is defined as follow:

$$\max z = \sum_I VP_i \times \frac{x_i}{T_i} \qquad (13)$$

Robust estimation

The parameters of data distribution are commonly estimated using classical estimators such as MLE. In this study the parameters of the model are estimated using data derived from Shahid Madani HIS. Such as every practical data, hospital data may contain contamination. So, at first the content of the data were reviewed. Due to the fact that data are contaminated, estimators insensitive to the contamination, robust estimators, are used to estimate the parameters. The details of MLE and robust estimators are described in this section.

Maximum likelihood estimation of the parameters

The probabilities $\theta_1, \theta_2, \ldots, \theta_m$, respectively. So, the probability mass function of *Y* is defined as follow:

Y	1	2	...	M
P(Y=y)	Θ_1	Θ_2	...	Θ_m

(14)

The probability mass function may define as follow:

$$P(Y = y) = f_Y(y) = \theta_1^{I(y=1)} \theta_2^{I(y=2)} \ldots \theta_m^{I(y=m)} \qquad (15)$$

Where *I(.)* is the indicator function.
Let $Y_1, \ldots, Y_n$ denote a random sample of size *n* with probability mass function $f_Y(y)$. Thus, the likelihood function of this random sample is defined as follow:

$$L(\theta_1, \theta_2, \ldots, \theta_m) = \theta_1^{\#(y_i=1)} \theta_2^{\#(y_i=2)} \ldots \theta_m^{\#(y_i=m)} \qquad (16)$$

Where *#(A)* denotes the number of elements of set *A*.
By defining the sample proportion f_i, we have:

$$f_i = \frac{1}{n} \sum_{j=1}^{n} I(y_j = i) \qquad i=1, 2, \ldots, m \qquad (17)$$

Thus:

$$L(\theta_1, \theta_2, \ldots, \theta_m) = \theta_1^{nf_1} \theta_2^{nf_2} \ldots \theta_m^{nf_m} \qquad (18)$$

By defining $L^* = L^{\frac{1}{n}}$ and $l^* = \log L^*$, we have:

$$l^*(\theta_1, \theta_2, \ldots, \theta_m) = \sum_{i=1}^{m} f_i \log \theta_i \quad (19)$$

$$s.t: \sum_{i=1}^{m} \theta_i = 1$$

Solving the above optimization problem yields to:

$$l^* = -\sum_{i=1}^{m} \rho(\frac{f_i}{\theta_i})\theta_i + A \quad (20)$$

Where A does not depend on $\theta_1, \ldots, \theta_m$. Also in Equation (20) $\rho(x) = x \log x$ is used. In order to estimate $\theta_1, \ldots, \theta_m$ the value of A-l^* shall be minimized. Estimating the values of $\theta_1, \ldots, \theta_m$ needs the following mathematical programming to be solved:

$$\min Q = \sum_{i=1}^{m} \rho(\frac{f_i}{\theta_i})\theta_i \quad (21)$$

To solve the above defined mathematical programming model, a Lagrange function is defined and related problem is solved. The MLE for parameters $\boldsymbol{\Theta}$ are defined as follows:

$$\hat{\theta}_i = f_i \quad (22)$$

Robust estimation of the values of the problem parameters

To estimate parameters of the developed model the data are derived from Shahid Madani HIS. So, it is possible that the data consist of contamination. So, robust estimators can be a good choice. Ruckstuhl and Welsh in 2001 [19], developed a new class of estimators for the binomial distribution parameter. Due to the discreteness nature of the distribution function of the estimated parameters, this study has been infused by the methods developed by Ruckstuhl and Welsh [19] in estimating parameters of the developed model robustly.
As it is shown in equation (20), the likelihood function of random sample is defined as:

$$Z = \sum_{i=1}^{m} \theta_i \rho\left(\frac{f_i}{\theta_i}\right)$$

Where:

$$\rho(x) = x \log x \quad (23)$$

When there is no contamination $\rho(x)$ is equal to *xlog x*. but if there is contamination in the data, it is better not to use *xlog x*. Hence this problem can be defined as an optimization problem in which the $\rho(x)$ is a function with special properties.

Table 3 - Surgical groups demand and hospitals in Alborz province

Hospital	**Surgical group**									
	CNS	**ENT**	**Orology**	**Orthopedic**	**Eye**	**Hand**	**Burn**	**Vascular**	**General**	**Maxillofacial**
Rajaei	*							*	*	
Kamali			*	*					*	
Bahonar		*	*	*	*	*			*	
Hazrat Ali										
Sarallah			*	*	*				*	
Shariati	*	*	*	*	*			*	*	
Imam Khomeini	*	*	*	*	*				*	
Qaem	*	*	*	*	*			*	*	
Alborz	*	*	*	*	*				*	
Eshtehard									*	
Referral number	5	5	7	7	6	1	0	3	9	0
Demand	441	297	382	4784	936	815	122	194	2440	102

$$Min\ \ Z = \sum_{i=1}^{m} \theta_i \rho\left(\frac{f_i}{\theta_i}\right)$$

St:

$$\sum_{i=1}^{m} \theta_i = 1$$

$\theta_i \geq 0 \qquad \forall\ i = 1,2,\dots,m$

which is the same as writing: $\theta_i - s_i^2 = 0 \qquad \forall\ i = 1,2,\dots,m$ (24)

Lagrangian multiplier method is used to solve the above mathematical model. The Lagrange function of the problem can be defined as fallow:

$$Z = \sum_{i=1}^{m} \theta_i \rho\left(\frac{f_i}{\theta_i}\right) - \lambda\left(\sum_{i=1}^{m} \theta_i - 1\right) - \sum_{i=1}^{m} \mu_i\,(\theta_i - s_i^2) \tag{25}$$

Where all the variables are free. Θ is used as decision variable vector, so:

$$\Theta = (\theta_1, \theta_2, \dots, \theta_m, \lambda, \mu_1, \mu_2, \dots, \mu_m, s_1, s_2, \dots, s_m)' \tag{26}$$

To solve the optimization problem, Equation (25), the gradient must be calculated as follows:

$$F = \frac{\partial Z}{\partial \Theta} \tag{27}$$

If:

$$\rho(x)' = \Psi \quad \text{and} \quad \Psi(x)' = \xi(x) \tag{28}$$

Then:

$$\frac{\partial Z}{\partial \theta_j} = \rho\left(\frac{f_j}{\theta_j}\right) - \theta_j \times \frac{f_j}{\theta_j^2}\Psi\left(\frac{f_j}{\theta_j}\right) - \lambda - \mu_j$$

$$\frac{\partial Z}{\partial \theta_j} = \rho\left(\frac{f_j}{\theta_j}\right) - \frac{f_j}{\theta_j}\Psi\left(\frac{f_j}{\theta_j}\right) - \lambda - \mu_j \qquad \forall\ j = 1,2,\dots,m$$

$$\frac{\partial Z}{\partial \lambda} = -\left(\sum_{i=1}^{m} \theta_i - 1\right)$$

$$\frac{\partial Z}{\partial \mu_j} = -\theta_j + s_j^2 \qquad \forall\ j = 1,2,\dots,m$$

$$\frac{\partial Z}{\partial s_j} = 2\mu_j s_j \qquad \forall\ j = 1,2,\dots,m \tag{29}$$

And

$$F(\Theta)_{3m+1} = \begin{pmatrix} \rho\left(\frac{f_1}{\theta_1}\right) - \frac{f_1}{\theta_1}\Psi\left(\frac{f_1}{\theta_1}\right) - \lambda - \mu_1 \\ \vdots \\ \rho\left(\frac{f_j}{\theta_j}\right) - \frac{f_j}{\theta_j}\Psi\left(\frac{f_j}{\theta_j}\right) - \lambda - \mu_j \\ \vdots \\ \rho\left(\frac{f_m}{\theta_m}\right) - \frac{f_m}{\theta_m}\Psi\left(\frac{f_m}{\theta_m}\right) - \lambda - \mu_m \\ -(\sum_{i=1}^{m} \theta_i - 1) \\ -\theta_1 + s_1^2 \\ \vdots \\ -\theta_j + s_j^2 \\ \vdots \\ -\theta_m + s_m^2 \\ 2\mu_1 s_1 \\ \vdots \\ 2\mu_j s_j \\ \vdots \\ 2\mu_m s_m \end{pmatrix} \tag{30}$$

In order to solve the optimization problem, $F(\Theta) = 0$ shall be solved. According to the non-linearity of some equations in the above system of equations, Newton-Rophson method is applied. Thus:

$$\Theta^N = \Theta^O - J_{\theta_O}^{-1} F(\Theta^O) \tag{31}$$

Where Θ^N is defined as an estimation for new value of the root while Θ^O and J represent the current value of the root and Jacobian matrix of system of equations respectively. To form the Jacobian matrix the gradient of F must be calculated for each variable. Equation (32) shows the Jacobian matrix.

$$J_{\theta_0} = \begin{bmatrix} \frac{f_j^2}{\theta_j^3}\xi\left(\frac{f_j}{\theta_j}\right) I_{m\times m} & -1_{m\times 1} & -I_{m\times m} & 0_{m\times m} \\ -1_{1\times m} & 0_{1\times 1} & 0_{1\times m} & 0_{1\times m} \\ -I_{m\times m} & 0_{m\times 1} & 0_{m\times m} & 2s_j I_{m\times m} \\ 0_{m\times m} & 0_{m\times 1} & 2s_j I_{m\times m} & 2\mu_j I_{m\times m} \end{bmatrix} \tag{32}$$

The new value for Θ^N will be obtained, substituting the

matrix provided in Equation (32) for J_{θ_0} in Equation (31). This will be repeated until convergence of the solution.
To define appropriate robust estimator, the $\rho(x)$ function proposed by Ruckstuhl and Welsh [19] is used. This $\rho(x)$ function is defined as follow:

$$\rho(x) = \begin{cases} (\log(c_1+1))x - c_1, & if \\ xlog(x), & if\ c \\ (\log(c_2+1))x - c_2, & if \end{cases} \quad (33)$$

In Equation (33), c_1 and c_2 are defined in such a way that resulting estimators have the highest robustness. Simulation results show that the values c_1=0 and c_2=1.7 lead to appropriate results for the defined robust estimator. The criteria using in this section is the asymptotic bias of estimation.

Results

The results presented in this section are based on the data collected from Shahid Madani hospital. To obtain the data required for this study, the data for a period of 16 months in the course of March 20, 2014 to July 21, 2015 were collected from Shahid Madani HIS. During this period, operating information related to 19846 patients was registered.
It is assumed that the opening hour of the OR is 8 hours a day and they are open 5 days a week. The minimum time required for each surgical group is calculated according to the maximum rate of decrease in the capacity of the surgical group *i* compared with that of the last year capacity. In this study the VP_i is considered as "value of patient" of surgical group *i* and weighted sum method is applied to calculate this value. Table 4 shows the objective function criteria and values of the estimated parameters of the model. Average duration of the surgery time and average LOS in the wards and the ICU are calculated using E robust estimator.

Table 4 - Value of the required estimated model parameters

Surgical group	Cap_i	DY_i	stw_i	stI_i	T_i	RN_i
CNS	58965	400	4.25	2.73	184	5
ENT	15871	271	1.71	1.94	73	5
Orology	27945	353	2.48	0.20	95	7
Orthopedic	244634	3398	3.28	0.20	115	7
Eye	50134	813	0.78	0.01	77	6
Hand	71418	748	2.99	0.16	115	1
Burn	9749	114	8.85	0.13	96	0
Vascular	3561	104	4.23	1.93	78	3
General	72565	885	3.24	0.34	105	9
Maxillofacial	7451	104	3.41	0.23	101	0

In order to find the optimal OR allocation the developed LP model is solved using GAMS software and data derived from the developed robust estimator. The results indicate that the proposed model obtains better solution, i.e. 31.2% higher than that of the current solution put in practice by the hospital. In order to study the effect of the OR available time on the objective function the proposed model has been solved in different scenarios in terms of available capacity of elective OR time. The results are presented in Figure 1.

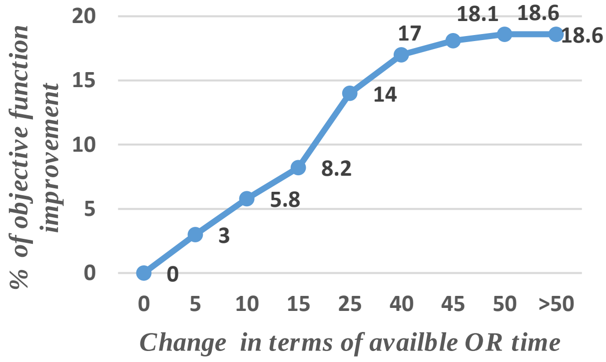

Figure 1. Objective function improvement against the change in the available OR time

As shown in Figure 1, increasing available OR time can improve optimum solution up to 18.6%. The reason behind facing with this increasing rate, may be attributed to the technical restriction on the OR facilities. This provides an opportunity for hospital managers to facilitate their idle operating rooms in order to support some other surgical groups if it will be possible.
The results of the sensitivity analysis also reveal that wards and ICU capacity are not a bottleneck in Shahid Madani hospital and hence the hospital managers shall focus on available OR elective capacity and their elective covering policy to improve the performance of OR.

Conclusion

This paper studied the problem of allocating OR time to surgical groups. For this purpose an LP model is developed to find optimum OR time allocation. Constraints and the parameters' values of the developed model are defined according to the data derived from Shahid Madani hospital. Based on the nature and policy of Shahid Madani, two criteria were considered as performance measures and a weighted sum method was applied to construct the "value of patient". To estimate the values of the model parameters, an E robust estimator was applied to down weight contaminations of the data. Then the developed LP model was solved using GAMS software. Computational results revealed that the results of solving developed model make an increase in total hospital operated "value of patient" by 31.2%. In addition a sensitivity analysis was conducted to study any potential of improvement in objective function. The results of the sensitivity analysis indicated that as the available OR capacity increases the value of the objective function considerably increased, while ICU and ward beds capacity changes did not affect the objective function. study the problem in an uncertain environment in terms of LOS in the wards, ICU or operating time can be some potentials to further study.

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