



Bed Capacity Planning Using Stochastic Simulation Approach in Cardiac-surgery Department of Teaching Hospitals, Tehran, Iran

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Abstract

Background: To determine the hospital required beds using stochastic simulation approach in cardiac surgery departments.

Methods: This study was performed from Mar 2011 to Jul 2012 in three phases: First, collection data from 649 patients in cardiac surgery departments of two large teaching hospitals (in Tehran, Iran). Second, statistical analysis and formulate a multivariate linier regression model to determine factors that affect patient's length of stay. Third, develop a stochastic simulation system (from admission to discharge) based on key parameters to estimate required bed capacity.

Results: Current cardiac surgery department with 33 beds can only admit patients in 90.7% of days. (4535 d) and will be required to over the 33 beds only in 9.3% of days (efficient cut off point). According to simulation method, studied cardiac surgery department will requires 41-52 beds for admission of all patients in the 12 next years. Finally, one-day reduction of length of stay lead to decrease need for two hospital beds annually.

Conclusion: Variation of length of stay and its affecting factors can affect required beds. Statistic and stochastic simulation model are applied and useful methods to estimate and manage hospital beds based on key hospital parameters.

Keywords: Hospital beds, Cardiac surgery department, Hospital stay, Stochastic simulation

Introduction

In recent years, research on the hospital planning and related topics including bed planning methods, operating theater scheduling, and waiting lists has been interested (1). For example bed capacity estimation is an interesting and key issue in hospital bed management (2). Bed management process includes patient experience, bed allocation, and, bed capacity planning. A suitable bed management method can help reduce patient's waiting time and decrease canceled surgeries because of hospital beds blocking. Note that the

balance of bed capacity and clinical processes can produce suitable outcomes for patients (3).

Today, different literatures relating to hospital bed planning and patient flow problems are increasing in the worldwide (4). Hospital bed capacity estimation is a complex issue because patient's stay and arrival of patients to a hospital is a stochastic process. There are also many kinds of hospital stays (from long-term to short-term) and several specialties each with its case management profile. Length of hospital stay is a key parameter

for bed capacity modeling (5, 6). Optimizing the hospital length of stay is promising alternative for efficient consumption of hospital beds and other resources (7, 8). Length of stay indicator is used for various purposes such as management of hospital care, quality control, and appropriateness of hospital resource use, bed management, and hospital planning (9).

Bed estimation and allocation is a macro-level type decision. A planned bed allocation to the different medical and surgical specialties is an important decision for hospital management. Today, researchers and planners use the simulation models for hospital bed capacity planning (10). A simulation can be used to response 'what-if?' in the basis of simulation models we can produce various scenarios for decision-making (11). Simulation is an appropriate tool for evidence-based decision making in complicated and uncertain systems such as health systems. This technique provides possible solutions through modeling (12)-14). In the recent decades, Simulation approach has been used to solve problems of health care sector and hospitals (13, 14). Using simulation approaches to improve health care systems has been facing with challenges and there are some barriers to implementation of simulation models (4, 11).

In different studies of health care system, researchers have used the mathematical simulation models including dynamic, static, deterministic, and stochastic models (15). Some of these simulation models can be used for hospital bed planning. One study describes three frequent simulation models for hospital planning; First, Discrete Event Simulation (DES), Second, System Dynamics (SD), Third, Agent-Based Simulation (ABS) that is a simulation method for modeling dynamic and autonomous systems (11).

Some studies recommended a mixed method to determine and estimate required resources of hospitals (10). Another study used stochastic simulation method to assess the number of beds required for gynecology departments in a university hospital in Tehran, Iran (18). Simulation methods and managerial scenarios are useful tools for hospital beds estimation (19).

Deterministic approaches cannot be used to assess requirements of complex and dynamic systems such as hospitals (16). Because Patient's arrival rate and its length of hospital stay, are stochastic processes (2, 10).

The main purpose of this study was to estimate hospital beds using stochastic simulation approach in cardiac surgery department of teaching hospitals.

Methods

Design and setting

This cross-sectional study was conducted in cardiac surgery department of Imam Khomeini and Shariati hospitals that belong to Tehran University of medical sciences, Iran. These are two teaching and large hospitals with 970 and 570 beds, respectively. Imam Khomeini hospital had 18 cardiac surgery beds, 8 cardiac surgery intensive care units and 39 cardiology beds. Shariati hospital has 8 cardiac surgery intensive care units, 7 post intensive care units and 22 cardiology beds. This study was performed in three phases: First, Data collection and identification of critical factors to determine required parameters of simulation model (including hospital stay, patient's arrival rate, and admission days). Second, statistical analysis and formulate a multivariate linear regression model to determine factors that affect patient's length of stay. Third, develop a stochastic model in order to simulate hospital admission system and estimate the hospital bed capacity.

Data collection and Study population

Data from 649 consecutive patients who underwent cardiac surgery between Mar 2011 and Jul 2012 were analyzed in order to determine factors affecting hospital stay.

Statistical analysis

Then we developed a predicted length of stay based on its affecting factors using linear regression model. The Validity of regression model was confirmed using agreement between observed and predicted rate of length of stay by paired *t*-

test. The paired *t*-test used to confirm fitness of model. The result of paired T-test showed that there was not any different between predicted and observed LOS ($P \geq 0.05$). Therefore, the model had a goodness of fit to predict the length of stay. The result of regression model is presented by the following equation:

$$y = \beta_0 + \beta_1 x_i + \beta_2 x_i + \dots + \epsilon_i \quad i=1, 2, 3, n.$$

Predicted LOS = -9.241 + Age of patients (0.065) + having social security insurance (1.536) + elective admission (3.184) + Admission in Thursday (2.47) + Spring admission (5.787) + Summer admission (4.380) + Fall admission (3.662) + having prior myocardial infraction (2.192) + Cross clamp time (0.041) - On-Pump (5.499) + the number of laboratory tests (0.127) + the number of clinical consultations (1.431).

Table 1: Multiple linear regressions analysis of factors associated with patient's length of stay

Factors	Unstandardized Coefficients		Standardized Coefficient	CI 95%		P Value
	B	S.E	Beta			
(Constant)	-9.241	3.264	-	-1.196	-11.144	0.005
Patients characteristics						
Age (continues)	0.065	0.029	0.096	0.015	-0.123	0.025
Medical insurance (Social Security Ins)	1.536	0.651	0.105	0.556	-2.868	0.019
Admission status						
Admission type (elective)	3.184	1.024	0.131	1.855	5.725	0.002
Admission day (on Thursday)	2.478	1.090	0.098	4.491	0.439	0.024
Season admission						
Spring	5.787	0.892	0.374	7.469	4.162	0.001
Summer	4.380	0.912	0.276	6.054	2.678	0.001
Fall	3.662	0.946	0.215	5.293	1.785	0.001
Risk Factors						
Prior MI	2.192	0.748	0.127	0.9850	3.739	0.004
Intra-operative factors						
Cross-clamp time (min)	0.041	0.018	0.098	0.007	0.074	0.024
On-Pump CABG	-5.499	1.115	-0.213	-7.481	-3.345	0.001
Consultation and laboratory services						
The number of laboratory tests	0.127	0.046	0.141	0.051	0.221	0.006
The number of clinical consultation	1.431	0.291	0.248	0.964	2.04	0.001

A stochastic simulation method

The patients arrival rate and their length of stay are stochastic processes and can be described by a Poisson distribution, and that the inter arrival time of patients; can be described by a negative exponential distribution (2, 17, 18). We used these distributions to describe our data. The following stochastic simulation steps were developed to determine the bed capacity of cardiac surgery departments: First, we determined the distribution functions for daily arrivals of pa-

tients, admission days and predictive LOS. Second, we generated 5000 simulated admission days for 10000 simulated patients using Poisson distribution. The average daily patient arrival rate was 2 patients per day ($\lambda=2$). According to this method, significant variables of predicted LOS were also simulated for 10000 patients. Third, it was constructed a stochastic simulation model using the obtained distributions (2, 18). Fourth, we calculated the required bed based on simulated patient arrival rate, predicted length of stay,

daily admission, discharge rate, and daily occupied beds. Daily occupied and unoccupied beds were calculated by following formula:

$$\text{Daily occupied beds (DOB)} = \text{available beds} + \text{same day discharge patients} - \sum \text{admissions patients}$$

Finally, we calculated the required number of cardiac surgery beds for the next 5000 d using the variation of daily occupied and unoccupied beds. Simulation and statistical analysis were performed by SPSS (SPSS software; Chicago, IL), R 3.1.0 software and EXCEL package.

Table 2 shows the status of admitted patients, discharged patients, and occupied beds in the first sixty admission days of 5000 simulated days. In the time of study, all beds (16 available beds) of cardiac surgery department were unoccupied. Therefore, we calculated the number of admitted patients, the number of discharged patients, occupied beds, and unoccupied beds for every day. Then excessive patients in every day were transferred to the next day if there was not any vacant bed in the same day. Therefore, the numbers of occupied beds were determined in every day until 5000 d.

Results

Table 2: Status of admission and discharge rate and occupied beds in the first 60 d(of 5000 days) based on 16 available beds

Admission days	The number of admitted patients	The number of discharged patients	Occupied beds*	Excessive patients (require beds)	Unoccupied beds	Admission days	The number of admitted patients	The number of discharged patients	Occupied beds	Excessive patients (require beds)	Unoccupied beds
1	1	0	1	0	15	31	1	1	18	2	0
2	1	0	2	0	14	32	1	1	18	2	0
3	2	0	4	0	12	33	2	2	18	2	0
4	2	0	6	0	10	34	1	3	16	0	0
5	2	0	8	0	8	35	4	1	19	3	0
6	3	0	11	0	5	36	2	1	20	4	0
7	4	0	15	0	1	37	4	6	18	2	0
8	1	0	16	0	0	38	2	2	18	2	0
9	3	3	16	0	0	39	3	2	19	3	0
10	4	1	19	3	0	40	2	0	21	5	0
11	1	2	18	2	0	41	1	0	22	6	0
12	1	2	17	1	0	42	2	2	22	6	0
13	1	0	18	2	0	43	1	2	21	5	0
14	4	2	20	4	0	44	4	2	23	7	0
15	4	1	23	7	0	45	1	3	21	5	0
16	0	0	23	7	0	46	2	1	22	6	0
17	3	2	24	8	0	47	4	2	24	8	0
18	0	1	23	7	0	48	0	4	20	4	0
19	1	4	20	4	0	49	4	0	24	8	0
20	0	1	19	3	0	50	3	4	23	7	0
21	1	2	18	2	0	51	3	0	26	10	0
22	4	4	18	2	0	52	2	2	26	10	0
23	3	1	20	4	0	53	3	3	26	10	0
24	2	4	18	2	0	54	2	2	26	10	0
25	1	2	17	1	0	55	1	2	25	9	0
26	1	1	17	1	0	56	1	1	25	9	0
27	3	1	19	3	0	57	2	3	24	8	0
28	1	2	18	2	0	58	4	2	26	10	0
29	2	1	19	3	0	59	0	5	21	5	0
30	2	3	18	2	0	60	2	1	22	6	0

Fig. 1 and 2 shows that available beds (16 beds) would occupy in 88.3% of days. The most number of occupied beds was 23 beds in 306 d (6.1% of days). The studied cardiac surgery department with 33 beds can admit all patients in 90.7% of d

(4535 d). Of course, the probability of need for over the 33 beds is very few that are cardiac surgery department will be required to over the 33 beds only in 9.3% of days (efficient cut off point).

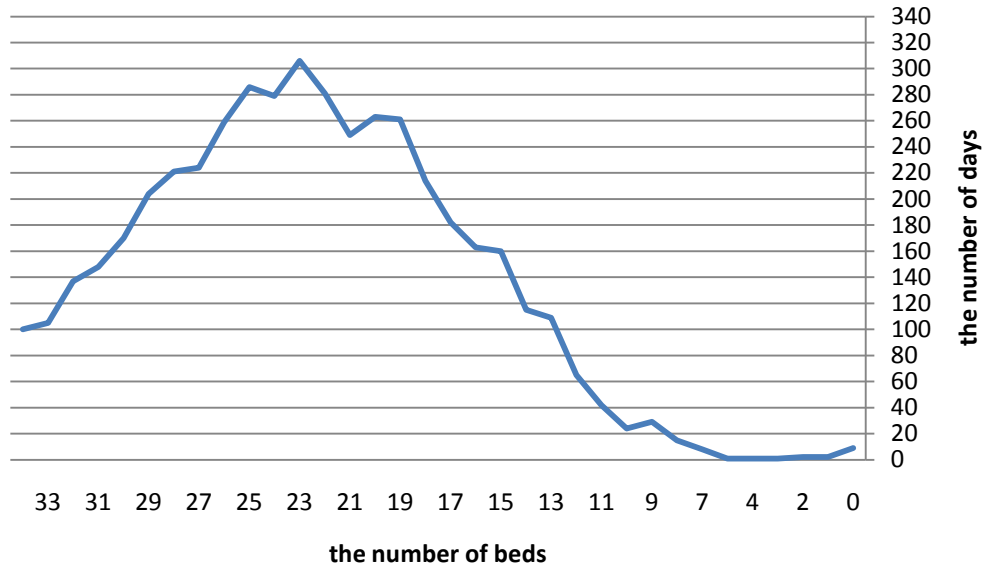


Fig. 1: The number of beds for 5000 simulated admission days

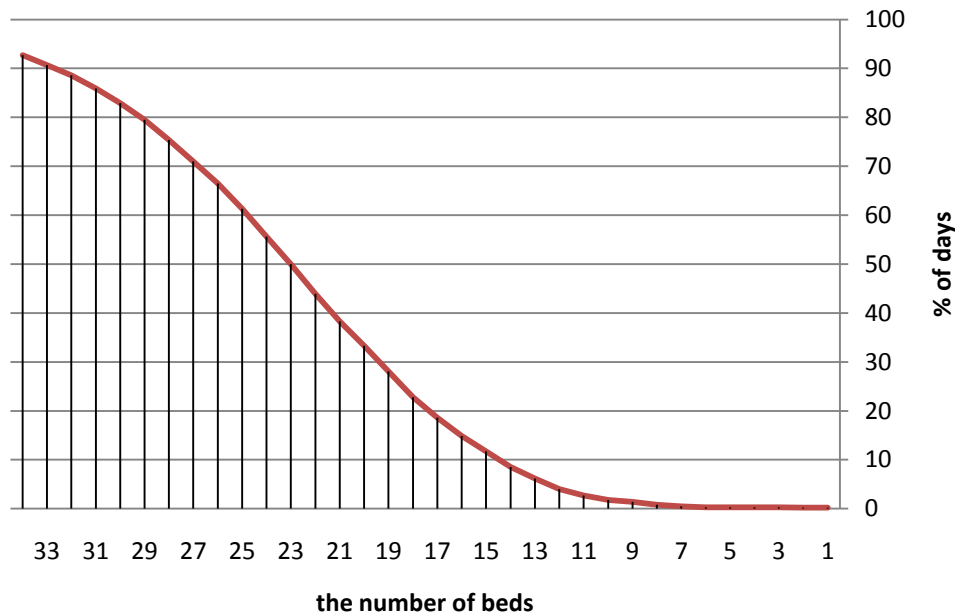


Fig. 2: Percent of days that occupied with beds

Furthermore, Table 3 shows that studied cardiac surgery department will require 21-30 hospital beds for admission of patients in 82.9% of next days (2479 d) and require 31-40 beds for admission of all patients in 98.7% of days. Table 4 shows that hospital can admit and hospitalize all referred patients with 41 beds in the third years, with 52 beds in the sixth years, with 46 beds in

the ninth yr, and 48 beds in the twelfth yr. According to simulation method, the results showed that cardiac surgery department in studied public and teaching hospitals will requires 41-52 beds for admission of all patients in the 12 next years. Finally, the results showed that reduce one-day length of stay lead to decrease two hospital beds annually.

Table 3: Categorized required beds for the next 5000 days

Occupied beds	The number of days	Percent of days (%)	Cumulative percent of days (%)
0-10	92	1.8	1.8
11-20	1574	31.5	33.3
21-30	2479	49.6	82.9
31-40	788	15.8	98.7
50<	67	1.3	100
Total	5000	100	-

Table 4: Scenario of required beds of cardiac surgery department for the twelve-year (4380 future days)

Required beds	Required bed capacity for 50% of d		Required bed capacity for 90% of d		Required bed capacity for 100% of days	
	Based on predicted	Based on predicted	Based on predicted	Based on predicted	Based on predicted	Based on predicted
	LOS-1	LOS	LOS-1	LOS	LOS-1	LOS
Categories of years						
First three-yr(1-3)	21	23	30	32	39	41
Second three-yr(4-6)	22	24	31	33	50	52
Third three-yr(7-9)	23	25	33	35	44	46
Forth three-yr(10-12)	22	24	32	34	46	48

Discussion

Estimation and utilization of hospital beds is an important issue for hospital managers and health policy makers (19). Estimation of the number of hospital beds depends on many parameters and factors. Some of them are not controllable by hospital managers. These issues have created the problems in term of calculation and estimation of hospital beds size.

To solve this problem, statistic models and simulation approaches are recommended to assess the number of beds required for hospital departments. On the other hands, the patients come into a hospital randomly. Arrival rate of patients is based on Poisson distribution (2, 11).

Therefore, it should be used a stochastic simulation model to determine patients distribution and estimate the number of required hospital beds. Stochastic methods are useful method to predict the future beds based on arrival rate of patients and their admission system. A study used stochastic simulation method to assess the number of beds required for gynecology departments in a university hospital in Iran (20).

In this study, we also developed similar statistic simulation method to estimate hospital beds for cardiac surgery department. This simple and applied method is more accurate and useful than other methods. In statistic simulation method, key managerial parameters of hospital are mod-

eled and then required hospital beds is estimated based on distribution of parameters for future years. One of the complications of the current method is the dynamic nature of some parameters such as population changes, risk factors variations, and patient's hospitalization pattern. Similarly, at the district general hospital, the reductions in hospital stay and admission rate had a great effect on the number of beds needed for a department (21).

Length of stay is an important criterion for hospital bed planning (25). This indicator can help estimation of required beds of hospital departments (7, 22). Of course, average length of stay is a rare rate and it is not useful for estimation of bed capacity alone. The bed size capacity should be estimated based on adjusted length of stay parameter (23). However, hospital stay indicator is affected by several risk factors; therefore, an adjusted LOS should be modeled based on its predictors (24, 25).

We calculated the predicted length of stay based on its affecting factors using multiple regression analysis. The results of regression analysis showed that for every unit increase in age, a 0.069 unit increase in LOS is predicted. The age of patients, have a positive correlation with length of stay (26-29). Cardiac surgery in the elderly patient requires longer intubation, longer ICU stay, longer hospital stay, and more beds (30). Whereas the proportion of elderly patients is projected to double in Iran for the next years (31) therefore, we projected that cardiac surgery beds will increase in future (13, 14).

Other study used a simulation method to estimate bed occupancy rate in cardiac surgery departments in Tehran, Iran (16). In our study, the arrival rates, admission days, length of stay and occupied beds were randomly simulated for 10000 patients and 5000 d (approximately 12 yr) in order to calculate the required bed capacity. The results of stochastic simulation method showed that studied surgery departments should increase their beds capacity to double in next years. Studied hospitals will be able to admit all their referred patients with 41 available beds in the first 3 yr (from 2011 to 2014). Totally, studied

cardiac surgery departments will require 48 hospital beds to admit all referred patients in the 12 next years. Increase the hospital length of stay increase the need for future beds (18-20).

This study showed that one-day excessive length of stay increased need for two excessive beds annually. Therefore, a well-managed hospital bed can decrease hospital costs. Many factors may affect the suitable use of hospital beds. There was a relationship between bed supply and bed demand. Bed reductions affect the use of remaining beds (32).

Here, Roemer's Law says "*hospital beds that are built tend to be used*" (33). Therefore, hospital managers should apply the bed management process and regulate supply and demand chain (34). Stochastic simulation method was useful tools for hospital beds estimation. Effective management of remaining hospital beds can reduce the need for more beds in future (35). Therefore, hospital managers can use two scenarios to response future needs: First, reduction of inappropriate length of stay (efficient strategy) and second increase of available beds (inefficient strategy).

Conclusion

Statistic and stochastic simulation model are applied and useful methods to estimate and manage hospital beds based on key hospital parameters including LOS, admission rate, and discharge rate. Generally, these parameters (e.g LOS) are available in hospitals and hospital managers can analyze these data by simple statistic and economic software in order to manage available beds. Therefore, we suggest that hospital managers and policy makers use the stochastic simulation approach to estimate and allocate beds and other resources efficiently.

Ethical Considerations

Ethical issues including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc. have been completely considered by the authors.

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