Original article

Dynamic simulation analysis for optimal sickbed allocation in a hospital

Kensuke Moriwaki[1], Shinichi Noto[2]

[1] Department of Health Informatics, Niigata University of Health and Welfare, Niigata, Japan
[2] Department of Occupational Therapy, Niigata University of Health and Welfare, Niigata, Japan

Key words : sub-acute stage sickbed, system dynamics, dynamic simulation model, hospital management, optimal sickbed allocation

Abstract

Objective: Quantitative analyses with combination of data on hospital performance and a mathematical modeling were conducted to evaluate optimal allocation of hospital sickbeds. Methods: Statistical analyses were performed to clarify potential factors which might affect length of (hospital) stay (LOS). In addition, model-based analyses by using methods of system dynamics were performed to elucidate optimal allocation of sickbeds in terms of hospital revenue. A hospital unit which consists of 16 sub-acute stage sickbeds and 44 normal sickbeds were modeled. In this model, hospital admission and discharge were modeled as “flows” which vary the number of patients in sub-acute sickbeds or normal sickbeds in chronological order. Annual hospital revenue derived from all hospitalizations was simulated varying the number of sub-acute stage sickbeds from 10 to 28. Results: Statistical analyses showed advanced age of patients, a hospitalization from external institutions, and having two or more complications were significantly associated with prolonged LOS. Also LOS differed significantly depending on the disease groups. Model-based simulations indicated raising the number of sub-acute sickbeds was associated with an increase in the hospital revenue. Conclusion: Despite several technical challenges, a newly developed approach for optimal bed allocation would be helpful for decision makers and applicable to other hospitals.

Introduction

In recent years, we have faced with expanding medical spending because of an aging society, changes in the structure of disease, and development of new health technologies. In Japan, inpatient treatment costs exceed 14.9 trillion yen, which account for the largest proportion of the total health expenditure and for approximately 40.7% of that [1]. Although the development of new health technologies is a key factor of growth in healthcare spending, hospitalization of the elderly for non-medical reasons including a shortage of nursing care facilities or family caregiver should be considered as other possible factors [2]. In such situation, the government has implemented reform of the healthcare system in order to moderate the healthcare spending and to efficiently use healthcare resources. Clarification of the division of the roles among medical institutions is one of the ways to control medical spending. Since the fourth revision to Medical Service Act in 2000, hospitals have been required to notify the type of

Corresponding author: Kensuke Moriwaki, MS
Department of Health Informatics, Niigata University of Health and Welfare
1398 Shimami, Kitaku, Niigata City, Niigata Pref., 950-3198, Japan
Telephone/Fax: +81-25-257-4536, E-mail: moriwaki@nuhw.ac.jp

sickbed with a choice of "normal sickbed" or "chronic stage sickbed" [3]. Also the Diagnosis Procedure Combination system has been introduced in hospitals, which provide medical service for acute stage inpatients since 2003 [4]. Consequently, healthcare services for acute stage and chronic stage have been clearly differentiated.

However, there has been growing demand for health service for sub-acute stage patients who are repeatedly hospitalized and released because of some reasons such as acute exacerbations of chronic diseases [5]. Therefore, during the revision of the Japanese medical fee schedule in 2004, the inpatient management fee for sub-acute stage was newly-created and applied for sickbeds which provide healthcare services for patients who experienced acute-phase treatment or got worse in a home-care setting [4]. Hospitals having sub-acute stage sickbeds are also expected to assist patients to comeback in a homecare setting and to cooperate with long-term care facilities in community. The number of hospitals applying for authorization of the inpatient management fee for sub-acute stage has been increasing [5]. Depending on the medical demand in community, hospitals have been required to prepare the medical care system for sub-acute stage patients. In particular, optimal allocation of hospital beds between normal sickbeds and sub-acute stage sickbeds has become an important issue in terms of not only community medical program also hospital revenue. Previous studies estimated optimal number of Neonatal Intensive Care Unit (NICU) beds by using Monte-Carlo simulation methods from a perspective of Japan society [6,7]. However there have been few studies which quantitatively evaluate the optimal allocation of inpatient sickbeds by disease stage from a perspective of hospital management.

The purpose of this study was to develop a new approach to support rational decision making on allocation of hospital sickbeds in terms of hospital management. This study consists of two analyses as follows: 1) Statistical analyses to clarify potential factors which might affect length of the hospital stay (LOS) based on data obtained from a hospital in Niigata prefecture, and 2) Simulation analyses to elucidate optimal allocation of sickbeds in terms of hospital revenue by combining the hospital data with a mathematical modeling.

Method

1. Data collection and basic statistical analysis

Data of hospital admission and discharge at an inpatient ward of "A" hospital which has 60 sickbeds between October 1st, 2009 to September 30th, 2010 was collected and retrospectively analyzed. This study was conducted complying with the principles described in the Declaration of Helsinki, and the research protocol was approved by the Institutional Review Board in Niigata University of Health and Welfare, and "A" hospital. Collected data items were as follows: age, sex, length of hospital stay (LOS), type of hospital sickbeds (sub-acute stage sickbed or normal sickbed), pre-hospitalization state (outpatient or other medical institution), date of admission, date of discharge, disease name coded by using ICD-10 (International Classification of Disease-10), complications, and secondary diseases. Patient characteristics were summarized, and the differences in LOS among disease groups were compared by using the Kruskal-Wallis test, followed by the Mann-Whitney U test and an appropriate correction for multiple comparison.

2. Multivariate analysis

Several factors potentially affecting LOS were evaluated through a multiple linear regression analysis. Dependent variable was logarithmic LOS. Several independent variables were considered in the multiple regression model as follows: Age, Sex ("Men" or "Women"), Type of hospitalization ("Normal sickbed" or "Sub-acute stage sickbed"), pre-hospitalization state ("Outpatient" or "Other medical institutions"), Complications ("with 0 or 1 complication" or "with 2 or more complications"), Secondary disease ("without secondary disease" or "with secondary disease"), and ICD-10 code. ICD-10 code was divided into four groups: M-code, S- or T-code, Z-code, and other code. M-code indicates "Diseases of the musculoskeletal system and connective tissue". S- or T-code show "Injury, poisoning and certain other consequences of external causes". Z-code shows "Factors influencing health status and contact with health services". Dummy variables were created for each code group and analyzed in the regression model.

Also a binomial variable indicating whether LOS exceeds 90 days or not was created, and logistic regression analysis was performed to identify factors affecting increased LOS more than 90 days. Independent variables considered in the multiple regression analysis were used for the logistic regression analysis. We used Stata/SE 9.0 for Windows (StataCorp LP) and PASW Statistics 18 (IBM) for a series of statistical analyses.

3. Simulation based on system dynamic modeling

Simulation analysis based on system dynamics was performed to quantitatively evaluate optimal allocation between sub-acute stage sickbeds and normal sickbeds in a rehabilitation unit located in "A" hospital. A dynamic simulation model was developed as shown in Figure 1 and analyzed by using iThink v9.0.3 (isee systems, inc). System dynamics is a way of thinking about the future which focuses on "stocks" and "flows" within processes and the relationships between them. In recent years, the system dynamics methodology has frequently been applied to healthcare issues [8-11]. In this study, the number of patients in

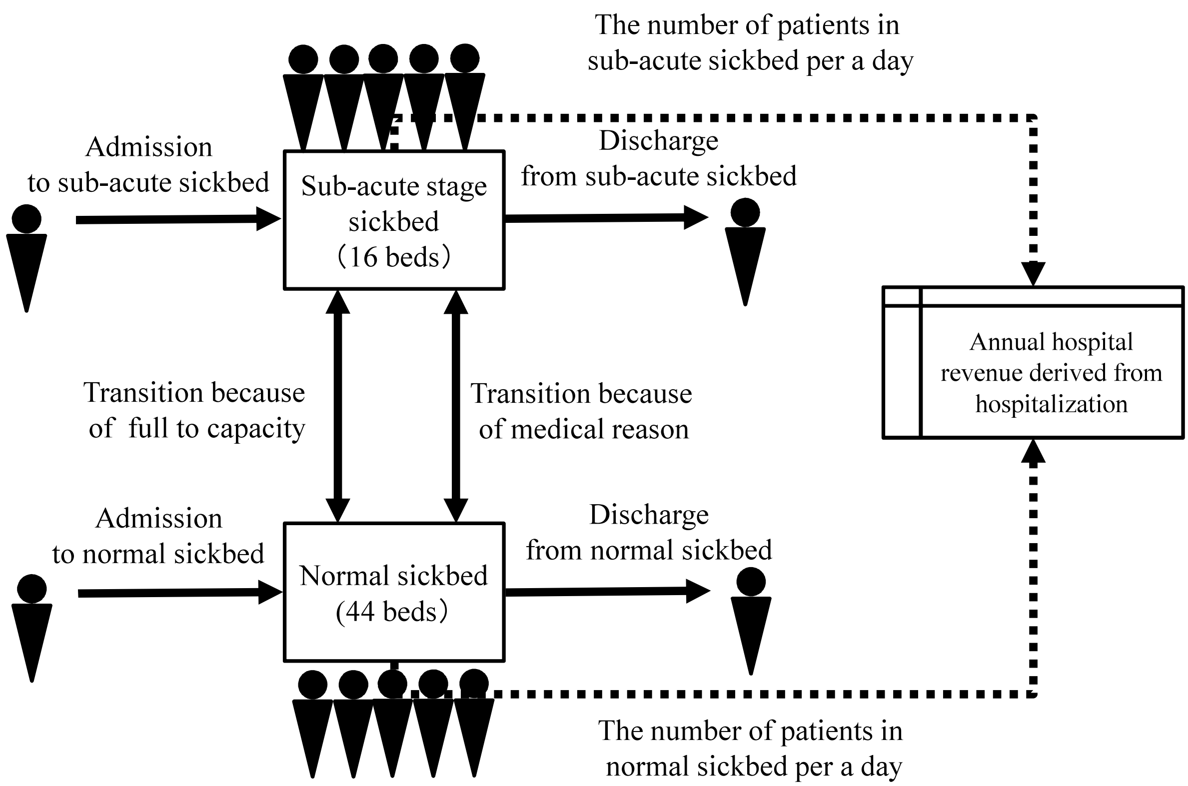


Figure 1. Structure of dynamic simulation model

sub-acute stage sickbed and normal sickbed were modeled as “stocks” which were cumulative values. The number of sub-acute stage sickbed and normal sickbed was set at 16 and 44, respectively (Table 1). Based on the obtained data from the hospital, an initial value of the number of patients in sub-acute stage beds and general beds was set at 7 and 40, respectively. In this model, hospital admission, discharge, and transition between sub-acute sickbeds and normal sickbeds were modeled as “flows” which vary the value of “stocks” in chronological order. These flows were applied for sub-acute stage sickbeds and normal sickbeds, respectively. In case of full to capacity of sub-acute sickbed or normal sickbed, patients were assumed to move to available sickbed.

Admission rate, transition rate, and discharge rate in sub-acute sickbeds and normal sickbeds were estimated based on the hospital data (Table 2). Time horizon was set at 1 year (365 days). Changes in the number of inpatients were simulated at daily intervals. Annual inpatient management fee, which consists of annual basic charge for normal sickbeds and annual inpatient management fee for sub-acute stage was estimated by using the simulation results. The basic charge for normal sickbeds was calculated as the number of patients in normal sickbed multiplied by 9,340 JPY per case day (Table 1) [12]. The inpatient management fee for sub-acute stage was calculated as the number of patients in sub-acute sickbed multiplied by 20,250 JPY per case day (Table 1) [12]. Also we performed sensitivity analyses varying the number of sub-acute stage sickbeds from 10 to 28 and simulated variations in the number of patients in sub-acute sickbed and annual hospital revenue derived from all hospitalizations.

Results

1. Patient characteristics and basic statistical analyses

The patient characteristics were summarized as shown in Table 3. Vertebral fracture and knee osteoarthritis were seen in the M-code group. We often saw hip fracture in the S- and T- code group. Convalescence following surgery was the most common state in the Z-code group. In the other code group, we saw carpal tunnel syndrome

Table 1. Parameter inputs used in the model

Item	Value (Range)	Reference
The number of total beds	60	Obtained data
The number of normal sickbeds	44 (32-50)	Obtained data
The initial number of patients in normal sickbeds	40	Obtained data
The number of sub-acute stage sickbeds	16 (10-28)	Obtained data
The initial number of patients in sub-acute stage sickbeds	7	Obtained data
Basic charge for normal sickbeds (JPY per case day)	9,340	[12]
Inpatient management fee for sub-acute stage (JPY per case day)	20,250	[12]

Abbreviation: JPY (Japanese yen)

Table 2. Parameter inputs for hospital admission, discharge, and transition

	Sub-acute stage sickbed			Normal sickbed		
Month	Admission rate (case per a day)	Transition to normal sickbed (case per a day)	Discharge rate (case per a day)	Admission rate (case per a day)	Transition to sub-acute stage sickbed (case per a day)	Discharge rate (case per a day)
1	0.0986	0.0000	0.0986	1.0849	0.0658	1.0849
2	0.1315	0.0000	0.1973	0.7233	0.0658	0.6904
3	0.0986	0.0329	0.0986	0.9205	0.0000	0.8877
4	0.0329	0.0000	0.0658	0.9205	0.0000	0.7562
5	0.0986	0.0329	0.0658	0.8877	0.0658	1.0521
6	0.0986	0.0329	0.1644	0.9534	0.0986	0.7562
7	0.1315	0.0329	0.1644	0.8877	0.0658	0.9863
8	0.2630	0.0329	0.1315	0.6575	0.0658	0.7890
9	0.2959	0.0986	0.1973	0.4932	0.0986	0.6575
10	0.3288	0.0000	0.2959	0.7233	0.1315	0.7562
11	0.2630	0.0329	0.3288	0.5260	0.0658	0.7562
12	0.0986	0.0000	0.0986	1.5452	0.0658	1.0192

Abbreviation: LOS (Length of (hospital) stay)

and so on. The median LOS was estimated to be 48 days, 34.5 days, 66 days and 10days for the M-code, S-/T-code, Z-code and other code, respectively. Z-code group showed the longest LOS, and other code group showed the shortest LOS among the groups (Figure 2).

2. Multivariate analyses

The result of multiple regression analysis was shown in Table 4. This showed LOS was affected significantly by age, pre-hospitalization state, complication and disease group. Also the result of logistic regression analysis to identify factors affecting increased LOS more than 90 days was shown in Table 5. Inpatient data of other disease group (18 cases) were excluded from this analysis because LOS of them were less than 90 days. The result indicated that hospitalization from other institutions affected increased LOS more than 90 days significantly, with odds ratio of 3.43 (95%CI: 1.47 - 7.96).

3. Simulation based on system dynamic modeling

The base case results of the dynamic simulation were shown in Figure 3. Base case analysis showed that sub-acute stage sickbeds had become full between the 260th day to the 300th day (Figure 3 (a)). Annual inpatient manageme nt fee for sub-acute stage sickbeds and annual basic hospital charge for normal sickbeds was estimated to be JPY 83,446,744 and JPY 124,439,056, respectively. The total came to JPY 207,885,799 (Figure 3 (b)). Also we performed a sensitivity analysis varying the number of sub-acute stage sickbed from 10 to 28 as shown in Figure 4. Setting the number of sub-acute stage sickbed at 10, 22, and 28 caused full to capacity of sub-acute stage sickbeds. The total hospital revenue derived from hospitalization was estimated to be JPY 197,162,711, JPY 207,885,799, JPY 228,938,155, and JPY 251,354,987 for the case of 10 sub-acute sickbeds, 16 sub-acute sickbeds, 22 sub-acute sickbeds, and 28 sub-acute sickbeds, respectively.

Table 3. Patient characteristics

	All patients (n=367)
Age (year)	67.1±21.9
Length of hospital stay (day)	53.2±72.9
Sex	
Men	149 (40.6)
Women	218 (59.4)
Types of hospitalization	
Normal sickbed	288 (78.5)
Sub-acute stage sickbed	79 (21.5)
Pre-hospital state	
Outpatient department	157 (42.8)
Other healthcare institutions	210 (57.2)
Complication	
With 0 or 1 complication	115 (31.3)
With 2 or more complication	252 (68.7)
Secondary disease	
Without secondary disease	338 (92.1)
With secondary disease	29 (7.9)
ICD-10 coding	
M-code	132 (36.0)
S- / T- code	108 (29.4)
Z-code	109 (29.7)
Other code	18 (4.9)

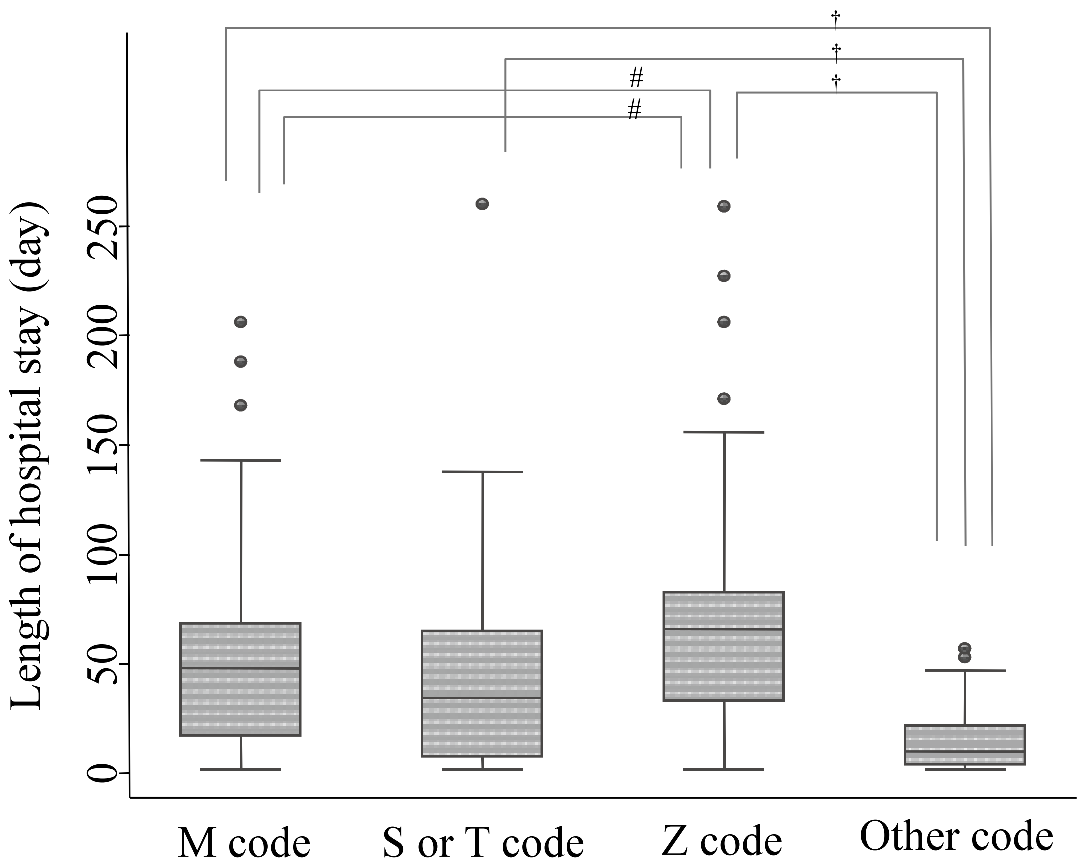
Abbreviation: ICD-10 (International Classification of Disease 10th revision)

Furthermore a sensitivity analysis was performed changing the value of discharge rate in sub-acute and normal sickbeds (Figure 5). Increase by 20% in the discharge rate from baseline was associated with 58.2% reduction in the total hospital revenue.

Discussion

In this study, we aimed to develop a new methodological framework to support rational decision making on optimal allocation of hospital sickbeds. Firstly, we examined potential factors which might affect LOS based on data from “A” hospital in Niigata Prefecture. Comparing the LOS among disease groups showed Z-code group such as convalescence following surgery had the longest LOS, and other code group had the shortest LOS among the groups. Multiple linear regression model indicated advanced age of patients, a hospitalization from external institutions, and having two or more complications were significantly associated with prolonged LOS. Also patients, who belonged to M-code, S-/T- code, and Z-code group disease, had longer LOS compared to those of other code group.

Under the current reimbursement system in Japan, a payment system for inpatient medical costs is switched from “fee-for-service” to “flat-payment”, if LOS exceeds 90 days. This means



†: Statistically significant p<0.05 v.s.Other code group, #: Statistically significant p<0.05 v.s. Z-code group

Figure 2. Comparison of LOS among disease groups

that LOS of 90 days is an important threshold in terms of hospital management. Therefore we used logistic regression to calculate the odds ratio of prolonged LOS over 90 days, while adjusting for possible confounders. We clarified that a hospitalization from external institutions was significantly associated with prolonged LOS more than 90 days with odds ratio of 3.43 (95%CI: 1.47 - 7.96). It would be helpful to make a brief prediction of LOS based on the factors identified in the multivariate analyses in terms of hospital management.

A series of statistical analyses had several limitations. In this analysis, the variable of pre-hospitalization state was created as binomial variable which simply represents “hospitalization from outpatient visit” or “hospitalization from external institutions”. Although there were a wide variety of institutions such as hospitals, clinics, special elderly nursing homes, healthcare facilities for the elderly and so on, we organized these external institutions into one category and used for statistical analyses because of limited sample size. Thus relative size of the impact on prolonged LOS more than 90 days among external institutions is not clear. It should be clarified based on an additional data analysis with enough sample size. Also we used alphabetic index of ICD-10 in grouping disease for convenience. However it seems to be difficult to interpret the results. More appropriate method for grouping disease remains to be solved.

Secondly, we conducted a simulation analysis based on system dynamic model to quantitatively

Table 4. Result of multiple regression analysis

	Coefficient	Standard error	95% CI	P value
Sex (Women=0, Men=1)	0.0439	0.1251	(-0.2022, 0.2899)	0.604
Age (yrs)	0.0186	0.0030	(0.0127, 0.0245)	<0.001*
Types of hospitalization (Normal=0, Sub-acute stage=1)	0.4441	0.1416	(0.1657, 0.7225)	0.103
Pre-hospitalization state (Outpatient=0, Other institutions=1)	0.3868	0.1158	(0.1590, 0.6146)	0.001*
Secondary disease (No=0, Yes=1)	0.2934	0.1941	(-0.0883, 0.6750)	0.157
Two or more complications (No=0, Yes=1)	0.6972	0.2031	(0.2978, 1.0965)	0.001*
Disease group				
ICD-10: M code (No=0, Yes=1)	1.0496	0.2516	(0.5548, 1.5444)	<0.001*
ICD-10: S or T code (No=0, Yes=1)	0.8263	0.2546	(0.3255, 1.3271)	<0.001*
ICD-10: Z code (No=0, Yes=1)	1.2725	0.2613	(0.7587, 1.7863)	<0.001*
Constant	0.2452	0.3264	(-0.3968, 0.8872)	0.527

F test: $p<0.01$, $R^2=0.368$, Adjusted $R^2=0.358$, Abbreviation: ICD-10 (International Classification of Disease 10th revision), 95%CI (95% confidence interval)

Table 5. Result of logistic regression analysis

	Odds ratio	Standard error	95% CI	P value
Sex (Women=0, Men=1)	0.6593	0.2743	(0.2917, 1.4899)	0.317
Age (yrs)	1.0126	0.0114	(0.9904, 1.0352)	0.268
Types of hospitalization (Normal=0, Sub-acute stage=1)	0.9841	0.4208	(0.4257, 2.2751)	0.97
Pre-hospitalization state (Outpatient=0, Other institutions=1)	3.4257	1.4732	(1.4747, 7.9582)	0.004*
Secondary disease (No=0, Yes=1)	1.6576	0.8500	(0.6067, 4.5288)	0.324
Two or more complications (No=0, Yes=1)	3.0944	3.3986	(0.3595, 26.6354)	0.304
Disease group				
ICD-10: M code (No=0, Yes=1)	1.4171	0.6054	(0.6134, 3.2740)	0.414
ICD-10: S or T code (No=0, Yes=1)	0.8368	0.3874	(0.3377, 2.0734)	0.7

Likelihood ratio test: $p<0.01$, Abbreviation: ICD-10 (International Classification of Disease 10th revision), 95%CI (95% confidence interval)

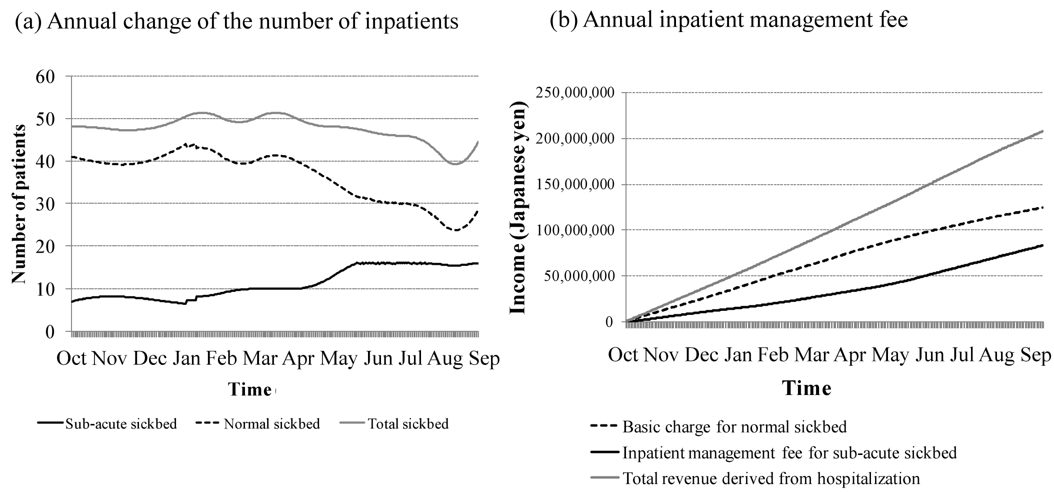


Figure 3. Base case results

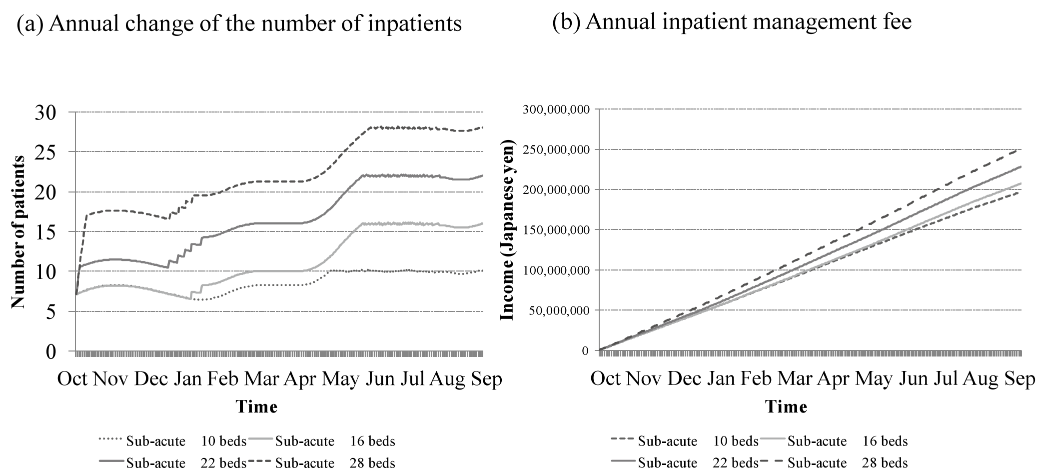


Figure 4. Results of sensitivity analyses for the number of sub-acute sickbeds

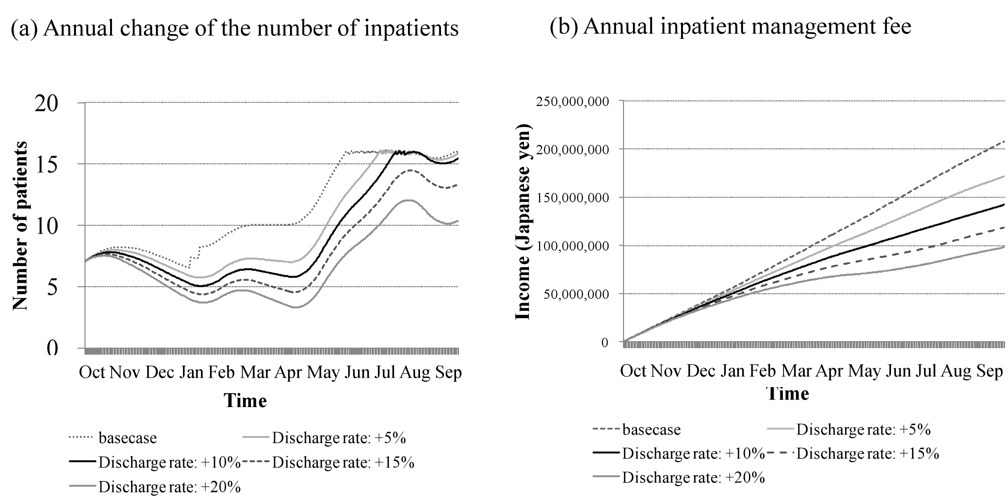


Figure 5. Results of sensitivity analyses for the discharge rate of sub-acute and normal sickbeds

evaluate optimal allocation of hospital sickbeds in a rehabilitation unit. A dynamic simulation model of hospital unit which consists of sub-acute stage sickbeds and normal sickbeds was successfully developed, and annual hospital revenue derived from hospitalizations was simulated. The results from simulation indicated that the number of sub-acute inpatients exceeded the number of sub-acute sickbeds for a period. This implied that the hospital unit had a temporary shortage of sub-acute stage beds. Annual hospital revenue derived from hospitalizations increased depending on the increase in the number of sub-acute sickbeds. The incremental revenue compared to the base case setting (16 sub-acute sickbeds) was calculated to be +21,052,356 JPY, and +43,469,188 JPY in the scenarios where the number of sub-acute sickbeds is 22 and 28, respectively.

In this analysis, however, we did not include cost items other than hospital management fee and basic charge such as treatment costs and manpower costs because such data were not necessarily available. Also we did not consider the change in hospital basic charge and management fee after 90 days to simplify the modeling [12]. Further studies based on a sophisticated model, including data on treatment costs and manpower costs in a hospital unit, are needed to precisely evaluate the impact of raising the proportion of sub-acute sickbeds on hospital revenue. Also the LOS predicted from multivariate model could be used to estimate a discharge rate (case per day) with different conditions by applying the following formula: discharge rate = current number of patients in beds / average length of hospital stay[13].

Despite several technical challenges, our approach has of great significance in supporting a decision making on hospital management. We believe that our approach for evaluating optimal bed allocation with combination of hospital performance data and a system dynamic modeling would be helpful for making a rational decision in terms of hospital management and be applicable to other hospitals.

References

1. Change in Medical Care Expenditure. Ministry of Health, Labour and Welfare; 2010. Available from: http://www.mhlw.go.jp/topics/medias/year/10/dl/iryouhi_data.pdf (accessed November 8, 2011) (in Japanese)
2. Ohta, S. Chiiki Care System. Tokyo: Yuhikaku ARMA; 2003. (in Japanese)
3. Tanaka S, Niki R. Hoken Iryo teikyo seido. Tokyo: Keiso shobo; 2006. (in Japanese)
4. Endo H, Ikegami N. Iryo hoken shinryo housyu seido. Tokyo: Keiso shobo; 2005. (in Japanese)
5. Takeda N. One consideration about the sub-acute stage sickbed. Niigata seiryo daigaku kiyo. 2006; 6:89-98. (in Japanese)
6. Takahashi H. How to determine the optimal number of hospital beds in a community - A trial by simulation - (Part 1). Gendai Igaku. 1986;33:569-573. (in Japanese)
7. Takahashi H. Determination of optimal number of bed and simulations. 2. Gendai Igaku. 1986; 34:169-174. (in Japanese)
8. Goldsmith D, Siegel M. Improving health care management through the use of dynamic simulation modeling and health information systems. Conference proceedings, the 29th International Conference of the System Dynamics Society; 2011. Available from http://www.systemdynamics.org/conferences/2011/proceed/papers/P1239.pdf (accessed November 8, 2011)
9. Haslett T. From hospital plans to computer simulation: a case study of the Alfred Centre. Conference Proceedings, the 25th International Conference of the System Dynamics Society; 2007. Available from

http://www.systemdynamics.org/conferences/2007/proceed/papers/HASLE498.pdf (accessed November 8, 2011)
10. Hwang LL. Explore the strategies of hospitals facing global budget and evaluate its effects in Taiwan. Conference Proceedings, the 23rd International Conference of the System Dynamics Society; 2005. Available from http://www.systemdynamics.org/conferences/2005/proceed/papers/HWANG287.pdf (accessed November 8, 2011)
11. Maliapen M, Dangerfield BC. A system dynamics-based simulation study for managing clinical governance and pathways in a hospital. Journal of the Operational Research Society. 2010; 61(2): 255-264.
12. Shinryo tensu hayami-hyo (Medical fee schedule in Japan). Tokyo: Igaku tsushin sya; 2010. (in Japanese)
13. Richmond B. An Introduction to Systems Thinking with iThink: High Performance Systems Inc; 2001.