Expert Systems With Applications 43 (2016) 142–153

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa

An integrated algorithm for performance optimization of neurosurgical ICUs

Ali Azadeh[a], Hossein Tohidi[b], Mansour Zarrin[a], Shima Pashapour[a], Mohsen Moghaddam[c,*]

[a] School of Industrial Engineering and Center of Excellence for Intelligent Based Experimental Mechanics, College of Engineering, University of Tehran, Tehran, Iran
[b] Mechanical and Industrial Engineering Department, University of Minnesota Duluth, Duluth, MN, USA
[c] PRISM Center & School of IE, Purdue University, West Lafayette, IN 47907, USA

ARTICLE INFO

Keywords:
Intensive care unit (ICU)
Performance optimization
Computer simulation
Data envelopment analysis (DEA)

ABSTRACT

This study presents an integrated simulation and data envelopment analysis (DEA) approach to increase the quality of service in a neurosurgical intensive care unit (ICU). The aim of this study is to capture the main factors which have negatively affects the patients' satisfactions and figure out their optimized levels. In order to avoid any interruption in ICU's routine functions and being able to convince the hospital's principals about the project's outcomes, a simulation model is developed and run for different scenarios. Then DEA is used to compare the outputs of different scenarios. These scenarios are generated by observing the effects of various parameters such as lengthening or shortening treatment times, decreasing or increasing patient volumes and removing or adding staff members. As the best of our knowledge, this is the first study that presents an integrated approach based on computer simulation and DEA to concurrently incorporate the stated factors and parameters for optimization of complex ICUs in developing countries. Therefore, the results of this study are more precise and reliable than previous studies because of concurrent consideration of the stated factors.

Motivation and significance

The demand for ICUs is increased. But, ICUs have not been significantly expanded, particularly in developing countries. Therefore, many patients should wait for admission in ICU, while delay in admission for such patients increases the risk of mortality. Also, lack of available ICU beds could lead to cancelation or postponement of many vital surgeries. The most important factors are the number of nurses in ICU and the number of ICU beds. This research is developed and presented to address the current shortcomings in ICUs. Moreover, it identifies the optimum number of physicians, operation rooms, ICU beds and nurses in such critical units.

1. Introduction

Patients who are in critical condition and their vital body's systems are impaired, will be admitted in ICU. These patients are unable to do any self-care. Therefore, they need to be in ICU. ICU was first used during World War II. ICU is usually established in large and equipped hospitals close to emergency centers and operating rooms (McVeigh, Moore, James, Hall, & Barnard, 2007). ICU can be categorized as general or specialized. Some hospitals, according to their surgical type, include some specialized ICUs in addition to general ICU; for example surgical ICU, internal ICU, neurosurgery ICU, cardiac surgery ICU, burns ICU, kidney transplant ICU, neonatal ICU and kids ICU. The mortality rate is usually high in general ICU. But, ICU should not be considered as a place for passing away of patients. Hence selection of patients for admission in ICUs is important. Patients who really need to have special care and requirement improvement are qualified for admission to ICUs (Simchen et al., 2007). The large hospital studied in this paper was established in 1948. Simulation studies are performed to analyze neurosurgical ICU performance capacity. The factors effect on mortality rate in ICU are studied in many researchers (Kim, Horowitz, Young, & Buckley, 1999; Mnatzaganian et al., 2008; Saukkonen et al., 2006; Sebat et al., 2007). In this regard, there are different approaches based on simulation (Lin, Sir, & Pasupathy, 2013). But most of the researchers focus on the lack of resources especially ICU beds (Cardoso et al., 2011; Carnes et al., 2011; Teres, 2004). There are many researches simulated other critical parts of the hospital or emergency department (Troy & Rosenberg, 2009a).

There are a lot of researches that assessed and evaluated the effect of delays in health care systems. Cardoso et al. (2011) analyzed a prospective cohort of adult patients admitted to an ICU between January and December 2005. A total of 401 patients were evaluated and it was proved that delay in general ICU admission increases ICU

* Corresponding author. Tel.: +1 765 430 4957.
E-mail addresses: aazadeh@ut.ac.ir (A. Azadeh), tohid002@d.umn.edu (H. Tohidi), mansour.zarrin@gmail.com (M. Zarrin), shima.pashapour@gmail.com (S. Pashapour), mmoghadd@purdue.edu (M. Moghaddam).

http://dx.doi.org/10.1016/j.eswa.2015.08.042
0957-4174/

mortality rates. Also, the results of their study show that there is a significant association between time to admission and survival rates. Wunsch, Harrison, Jones, and Rowan (2015) conducted a cohort study to determine whether the availability of High Dependency Unit (HDC) in a geographically separate unit affects patient flow or mortality for critically ill patients. They used data from adult general (mixed medical/surgical) critical care units participating in the Intensive Care National Audit and Research Centre Case Mix Program from January 2009 through December 2011. They assessed correlation using the Spearman correlation coefficient to assess the possible relationship between the availability of separate HDC beds and the percentage of patients discharged from the primary unit to the geographically separate unit. The results of this study indicated that availability of HDC in a geographically separate unit did not impact acute hospital mortality.

Rincon, Hunter, Schorr, Dellinger, and Zanotti-Cavazzoni (2014) conducted a multicenter retrospective cohort study in 94 ICUs in the United States to determine the temperature profiles and incidence of dysthermia among of brain injury patients who were admitted to the ICU and to assess the effects of dysthermia on in-hospital case fatality. Critically ill patients with neurological injuries who were older than 17 years and consecutively admitted to the ICU from 2003 to 2008 were selected for analysis. They conducted one-way ANOVA for evaluation of differences at a univariable level. According to their results, both early spontaneous fever and hypothermia conferred a higher risk of in-hospital death after brain injury. Harris, Singer, Rowan, and Sanderson (2015) did a prospective cohort study of deteriorating ward patients evaluated for critical care admission in National Health Service hospitals in the UK. They employed critical care occupancy as an instrumental variable, assuming that a full ICU could only affect outcome of a ward patient by deflecting or delaying admission. Their study was shown that the deteriorating ward patient was vulnerable with a high short-term mortality.

Borel, Schwebel, Planquette, Vésin, Garrouste-Orgeas, and Adrie, et al. (2014) conducted a comprehensive study and assessed whether the nutritional status of patients, which was defined by the body mass index (BMI) at admission in an ICU, affected the time of nutritional support initiation. They reported that the initiation of nutritional support was delayed in obese patients, possibly due to the subjective thought that their nutritional reserve was sufficient. Muthuri et al. (2014) conducted a meta-analysis of individual participant data to evaluate the relationship between neuraminidase inhibitor treatment and mortality (primary outcome), adjusting for both potential confounders and treatment propensity, using time-dependent Cox regression shared frailty modelling. Based on their results there was an increase in the mortality hazard rate with each day's delay in initiation of treatment up to day 5 as compared with treatment initiated within 2 days of symptom onset.

Hung et al. (2014) proposed a model to define delayed admission, and explored the effect of ICU waiting time on patients' outcome using data of non-traumatic adult patients on mechanical ventilation in the emergency department (ED), from July 2009 to June 2010. They used logistic regression analysis and showed that delayed ICU admission affected the outcomes of 21-ventilator-day mortality and prolonged hospital stay, with an odds ratio of 1.41. Bing-Hua (2014) analyzed a retrospective cohort of adult critically surgical patients admitted to our ICU between January 2010 and June 2012. By binary regression analysis (ICU outcomes as the dependent variable and other confounding factors as the independent variables), they identified potential correlation between delay in ICU admission and ICU outcomes. They indicated that there was a significant increase in ICU mortality rates with a delay in ICU admission.

According to the literature review, most of the previous studies employed statistical methods such as regression model to evaluate the effects of different factors (e.g. delay in ICU admission) on performance indicators in health care systems. In this study, an integrated approach based on using simulation and data envelopment analysis (DEA) is proposed to optimize efficiency of a health care system with respect to the different performance indicators. DEA is a linear programming model to maximize the efficiency of multiple decision-making units (DMUs) when the production process presents a structure of multiple inputs and outputs. In DEA model, one need not assume a priori the existence of a particular production function for aggregating and weighting inputs and outputs variables. Instead, the respective aggregation weights result from solving an optimization problem (Azadeh, Zarrin, Abdollahi, Noury, & Farahmand, 2015; Rickards, 2003). Hence, they are solely dependent on the empirical observations involved. This fact gives the DEA model a decisive advantage over ordinary optimization procedures (Lee, Hsu, Chou, & Guo, 2011).

The more erratic accuracy of ranking by DEA rather than regression analysis (RA) is entirely in keeping with the nature of the two methods. DEA efficiency estimates are based on a comparison of the input output levels of an individual DMU with those of a very small subset of efficient peer DMUs. Therefore, they can prove highly sensitive to data swings at the individual DMU level, whether the DMU concerned is that being assessed or a peer DMU. In contrast, RA efficiencies are based on estimated average parameter values in the regression model and they are therefore not very sensitive to data swings at the individual DMU level. It is interesting to see this observation as an extension of the comment made by Charnes (1994), that DEA assessments focus on the individual DMU and, as a result, offer more accurate results.

Furthermore, a simulation model is developed to cover the complete flow for the patient through the ICU and to understand the behavior of system in different situations. Simulation is one of the applicable and analytical tools for modeling the behavior of the real and complex systems such as ICUs that would otherwise be difficult to investigate. Simulation is an approach that is used most commonly in two situations: (1) when uncertainty is high due to sparse data and it is hard to run typical analytics on the limited historical data, so researchers use simulation to understand what happened to the tribe; and (2) for experimentation in a low-cost, low-risk environment. Proper descriptions of system behavior, forecasting and scenario analysis are some excellent capabilities of computer simulation models. Also, simulation models can be used for definition of deficiencies in the initial design process in low level of relatively cost.

Using simulation techniques have been widely used in different industries in the past decades (Gaba, 2007). Since the routine's functions cannot be interrupted in healthcare systems, there were an unprecedented growth in the application of simulation in this area. Making any improvement in neurosurgical ICU's equipment or procedures, based on its critical nature, needs to be confirmed by the hospital's principals. To be able to convince them about the final outcome, they need to have a great understanding of the systems after making the suggested improvement. Simulation tools and techniques as well as DEA provide them with this information before any changes to be made. Providing a comprehensive framework for checking the later changes in the system is the other advantages of the proposed methods. In addition, the proposed model is a cost effective approach because no changes will be done before assuring about its positive consequences. As a result there will be a saving in terms of resources, time and money.

On the other hand, using simulation has few demerits compare to previous approach which was usually based on real experiences. For instance in this case, it is possible to investigate the consequences of increasing or reducing the number of physicians in the system by applying these changes in reality. But these types of study might interrupt the system efficiency and also reduce the patients' safety during the study period but the result will be more reliable. In order to increase the reliability of the results using the simulation approach, a