A FRAMEWORK FOR EMERGENCY DEPARTMENT CAPACITY PLANNING USING SYSTEM DYNAMICS APPROACH AND THE THEORY OF CONSTRAINTS PHILOSOPHIES

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KEYWORDS:
Capacity planning, Emergency Department, System Dynamics, Theory of Constraints

ABSTRACT

Patient waiting time and service delivery problems characterize health care services and are more acute in an emergency department (ED). With more patients needing care and fewer resources to care for them, ED that operates at or above capacity is inevitable. This paper is a review of work-in-progress of a study being conducted in a government hospital in Penang, Malaysia. This paper proposes a hybrid of System Dynamics (SD) approach and the Theory of Constraints (TOC) in solving health capacity planning. The potential combination of these methods will be reviewed that is hoped to reveal the synergy between the established methods in addressing the health capacity planning options for the long-term future.

INTRODUCTION

Capacity planning is a strategic element in designing a system. It involves many decisions which may have long-term consequences for an organization. In capacity planning, all resources should be planned in a manner that can facilitate work flow across every process in the system. Ideally, capacity has to be matched with demand. However, in reality, capacity planning is a complex problem due to demand uncertainty, particularly in the service sector because services often cannot be stored (Barnes 2008). Hospital is a part of the service sector. With growing population and health care costs mounting, hospital is facing growing demand with lack of quantifiable data regarding its capacity (Ballard and Kuhl 2006). Lack of resource capacity, such as beds, doctors and nurses will cause overcrowding that can reduce health care quality by increasing the potential of medical errors and long waiting times, which leads to customer dissatisfaction with services (DeLia 2005). This scenario is inherently difficult in emergency care, because capacity decision is a major determinant for providing services over a specified time interval.

Acting as a critical entry to hospitals, the emergency department (ED) receives emergency patients at random and must be admitted with minimum delay and with priority over elective patients. A common perception of an efficient ED services usually relates to the availability of spaces, staff and equipments for emergency care in a timely manner (Kolb et al. 2007). Patients not only look at the result on the treatment provided, but they also consider the process of giving treatment. The smooth running processes in the ED are closely related to capacity planning (Baesler et al. 2003).

Much research in ED has focused on solving the operational problems that solves 'snapshot' problems and are not capable of drawing attention to the interdependency of the problem understudy. However, as many units integrate in a hospital, the ED service delivery also depends on other unit like the labs and wards. This problem is addressed here by proposing that simulation could be used to understand the structure and behavior of the system and is capable to create some strategic options for the future. It is worth noting that problems in the ED sometimes are originated from factors external to ED (Kolb et al. 2007).

In order to provide a better service and able to treat the surge in demand of different case mixes, this study attempts to give a 'big picture' view of the delivery process in ED. From a broader perspective, we hope to create a better understanding of the system that can be useful for policymaking. This paper starts with problems faced by a government's ED, followed by pertinent literature and the proposed methodology for the problem. Finally, the paper ends with a brief conclusion and the direction of future research.

MOTIVATION OF THE STUDY

In Malaysia, lack of medical staff has led to poor response time at most EDs around the country (News Strait Times 2008). The doctor-patient ratio in the country is recorded as 1: 1,105 (Health Informatics Centre 2009) which is lagged behind the developed

Proceedings 24th European Conference on Modelling and Simulation ©ECMS Andrzej Bargiela, Sayed Azam Ali David Crowley, Eugène J.H. Kerckhoffs (Editors)
ISBN: 978-0-9564944-0-5 / ISBN: 978-0-9564944-1-2 (CD)

countries. The shortage of doctors is predicted to continue and be more serious in government hospitals (Mohamed 2003). As a result, the public begins to advocate that government hospitals are not achieving the standard of efficiency displayed by private hospitals (Pillay 2009).

With the increased level of population, demand for health services particularly in the ED will also be increased (Hong and Ghani 2006). For instance, in the four-year period in Penang from 2005 to 2008, the number of attendances to an ED increased from 101,841 to 113,111. It represents an overall increase of 11.1%, which is higher than the 5.3% increase in Penang's estimated total population in the same period (SERI 2009). This situation has positioned the ED under increasing pressure to treat its patients within the expected timeline. With more patients needing care and fewer resources to care for them, ED that operates at or above capacity is inevitable. If this trend persists, what will happen to ED should there be a surge in demand in the future?

ED surge can be defined as a sudden increase in the demand for ED services while surge capacity is the resource availability in the hospital (McCarthy et al. 2006). Daily ED surge causes ED overcrowding in facilities that have inadequate resources to serve during the peak of demand. In other words, ED overcrowding is the result of a mismatch between ED surge and surge capacity (McCarthy et al. 2006). Surge capacity of an ED includes physical and personnel resources such as beds, doctors, nurses and pharmaceutical equipments.

Generally, in government hospitals, emergency patients are classified using three-color triage zone. Yellow and Red medical triage cards (MTC) are given to patients with semi-critical to critical illnesses, while MTC Green is assigned to non-critical patients. The surge in demand for emergency care associated with continually changing demand case mixes makes the ED an ever-changing system. This situation is tougher with the introduction of new target time for patient to be attended in the ED by Ministry of Health (MOH) in 2009 (refer Table 1). The new target time has put more pressure on ED staff as it must be achieved without additional resources.

Table 1: MOH's New Target Time

Medical Triage Card	**Time to be attended**	
	Prior	**New**
Red	immediately	immediately
Yellow	30 minutes	15 minutes
Green	2 hours	90 minutes

An ED with many critical patients usually will be out of control, pushing staff beyond their capacity to provide adequate care. This will prolong and breach the target times for patients who have been assigned with Yellow and Green medical triage card (MTC), as most of the resources are directed to treat patients with Red MTC. The absence of secondary triage also tends to increase patients waiting time because doctors have to examine the patients first before ordering for clinical tests if they were needed. Moreover, outgoing staff responding to ambulance calls exacerbates this situation as ED capacity will be depleted and thus increase the workloads among doctors and nurses to meet the incoming demand.

As ED generates new inpatients, whenever beds are fully occupied, they are placed in treatment area or hallway until an inpatient bed is available. Often times, pre-hospital care is also administered in the treatment area. These scenarios affect patients' flow, tie up space, equipment, and personnel that would otherwise be available to meet the needs of incoming patients. Will extra staff and new building be able to mitigate this turmoil? To make such capacity decision requires an understanding of the system behavior and the flow of the patients through the ED. The ED administrations believe that operation research/management science (OR/MS) approaches could furnish more information before they could commit to a particular course of action.

In the light of the above reasons, there is a need to develop a model representing the real environment of ED to examine and understand resource capacity and as well as to provide a framework that will consult hospital managers do the right decision to improve the service. In other words, a study should be done to determine if the current structure, staffing and physical resources are adequate to cope with a surge in demand. The question to be highlighted is whether ED is able to handle a sudden, unexpected surge in demand by using only the daily operating resources of the hospital. If sudden surges in ED exist, what are the relative effects to the labs and wards? Moreover, how quickly does ED recover from the unexpected surge in demand and how is this reflected in ED census?

This study aims to develop a system dynamics (SD) model that incorporates:

1. the service and flow of patients through the ED
2. the concept of Theory of Constraints (TOC) in capacity limitations
3. decision-making delays in regard to capacity limitations of the ED

This study would also investigate whether process bottlenecks in the system are related to low capacity in the department itself or stemming from factors external to ED. Though many units in the hospital have direct interaction with the ED, this study will only focus on the causality of various changes proposed in the ED to the labs and wards. In addition, this study examines surge capacity primarily in the context of responses within the hospital's environment or on its grounds that are managed and staffed by the hospital and does not rely on outside assistance.

A REVIEW OF RELATED RESEARCH WORK

Studies in health care capacity planning can be divided into three areas, i.e. bed planning, room planning and staff planning (Jun et al. 1999). However, forming as the main elements in hospital's capacity, these three areas should be studied in a single model to represent the complexity of resource planning in the realm.

A significant amount of research in health care has been conducted in EDs (Jun et al. 1999). This trend is probably attributed to the many problems encountered in the unit. Overcrowding, long waiting time are among the common problems faced by worldwide EDs. Several studies highlight that these problems are related to limited resources, which require proper planning and allocation (Kolb et al. 2007; Gunal and Pidd 2006).

Many researchers have been using OR/MS methods to solve problems in health care domains (Garg et al. 2008). However, simulation outnumbered other OR/MS approaches in health care (Davies and Davies, 1994) for at least three reasons: Firstly, healthcare systems require stochastic approach as there are many uncertainties and variability that are involved in the systems. Secondly, the complex nature of healthcare systems requires a modeling approach that can deal with complexity. Finally, human involvement in healthcare systems needs proper approach for interactions and communications between modeler and user (Brailsford 2007).

There are a few simulation approaches in healthcare such as discrete-event simulation (DES), system dynamics (SD), Monte Carlo simulation and agent based approach (Brailsford 2007). However, the most widely used simulation approach is DES, which has been used to analyze operations in many areas of healthcare like surgery department, clinics and pharmacies and as well as EDs (Spry and Lawley 2005; Gunal and Pidd 2006). This approach focuses more on operational characteristic without portraying the 'big picture' of the system. Unlike DES, SD can offer a better understanding of the 'big picture' by displaying the interactions and causality effects between elements in the system. There are quite a number of literatures on the application of SD modeling in the health care sector. (Koelling and Schwandt 2005; Dangerfield 1999; Royston et al. 1999) reviewed and discussed all previous studies conducted in the area of health care using system dynamics. These studies applied SD approach to solve problems revolved in healthcare such as patients' long waiting time, increasing demand on healthcare and resources allocation, infectious epidemic and community care.

However, thus far, the number of SD models in the context of healthcare planning is rather limited. Among them, the significant models are the works from (Brailsford et al. 2004; Lane et al. 2000 and Wolstenholme 1999). (Brailsford et al. 2004) developed a system dynamics model of the entire health care system in the city of Nottingham, England to simulate patients' flows and identifying the causes of bottlenecks in the health care system. Lane and his team, on the other hand, developed a model to investigate the relationship between waiting times in ED and bed closures. In other words, the study was conducted to see whether reduction in number of bed contributes to the high waiting time in ED. Study by Wolstenholme demonstrated the applications of SD in resource allocation issues. He studied the growing waiting list of elective surgery that was caused by emergency admission and non-elective admission of older people in winter.

Though many models of ED were constructed, those models mainly represent hospitals in the UK and Europe. The different factors and structures applied in these countries are not applicable in Malaysia e.g. technology development and triaging system. Besides, in Malaysia there is a disinclination to acknowledge policy transfer from both the west and neighboring countries, due to federal government control on the national political structure (Common 2004). Therefore, there is a need to find a specific model that can reflect ED in the country.

PROPOSED METHODOLOGY

At present, there is a growing concern on applying manufacturing philosophies to improve the health care system. Despite healthcare differs in many ways from manufacturing, there are also unanticipated commonalities. Whether producing a vehicle or providing healthcare for a patient, staff must rely on multiple, complex processes to accomplish their tasks and provide value to the customer or patient. In this regard, several hospitals in the United Kingdom have been implementing lean principles, six sigma methodology and theory of constraints (TOC) to improve operational performance, reduce operating costs, and improve the quality of service to patients (Young 2005).

Though many simulation studies in manufacturing have tested the combination of DES approach with manufacturing philosophies (Vollman et al. 2005), we could find little in the literature describing the combination of SD and manufacturing philosophies to improve the capacity planning in health care. Therefore, the combination of these approaches could help to understand the dynamic complexity of health system interactions and develop effective solution to improve health capacity planning.

This research is mainly concerned with the response and feedback actions among elements, delays and capacity constraints in the system being study. Feedback actions and delays are well established components of the SD discipline, whereas the concern of this study on capacity constraints is relative to the fact that any system will have at least one constraint as propounded in the TOC (Dettmer, 1998). The concept of managing constraints in TOC may help to identify the root of causes to constrained performance. Nevertheless, TOC may complement SD not only in generating an understanding of the problem, but also in discovering ways of solving them (Davies et al. 2004). TOC encourages further actions to be taken using the thinking process tools in identifying hurdles to implementation and conceive proper plans to get over the hurdles (Dettmer 1998). TOC thinking process consists of five logical tools that can be used individually or can be integrated. There are *Current Reality Tree (CRT), Conflict Resolution Diagram (CRD), Future Reality Tree (FRT), Prerequisite Tree(PT)* and *Transition Tree (TT).* For elaboration on these tools, readers are referred to other TOC text such as (Dettmer 1998) and (Lepore and Cohen 1999).

There are several stages usually involved in approaching a problem thinking using SD. Although different authors introduce different steps or phases in SD modeling process, the goal of each step is generally the same. In this study the modeling process suggested by Sterman (2000) and Maani & Cavana (2000) is modified and will be applied. The modeling process can be divided into six stages:

1. Problem Definition (Boundary Selection)
2. Formulation of Dynamic Hypothesis
3. Formulation of a Simulation Model
4. Model Testing
5. Policy Design and Evaluation
6. Strategy Implementation

In order to mix SD and TOC, this study is based on Mingers' framework for characterizing the philosophical assumptions underlying SD approach (refer Mingers 2003) and the framework by Davies et al. (2004) for characterizing the philosophical assumptions underlying TOC methods. By mapping both frameworks, we identify appropriate TOC thinking process to complement steps in conducting SD modeling as shown in Figure 1.

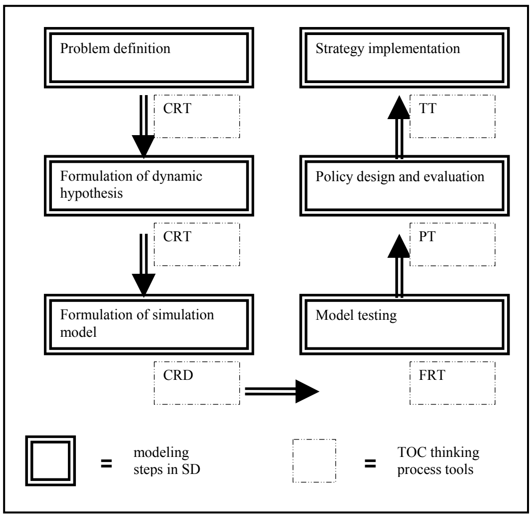

Figure 1: Steps in Conducting a System Dynamics Study and Applicable TOC Thinking Tools

At the initial phase, interviews with the ED administration have helped to identify the main actors of a potential model and the boundaries to the problem. The high level map of factors affecting ED services is summarized in Figure 2.

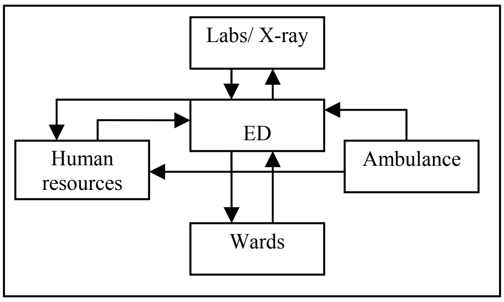

Figure 2: High-level map of factors affecting ED services

At this phase, the CRT will be used to list symptoms that indicate what is inappropriate within the system. During second phase, dynamic hypothesis will be developed. Causal loop diagrams will be constructed to reveal the dynamic hypothesis of problem understudy. The dynamic hypothesis is obtained from the patterns of behavior that arise from the relationship among elements in the system. In minor contrast, the CRT will also be used to capture the systemic nature of relationships within the system being modeled using undesirable effects to trace back the root of the problem. The different protocol offers by CRT will serve as complementary tool to causal loop diagrams in identifying the cause and effect chains of the problem.

On the next phase, with the assist of the CRD, a simulation model will be able to display any conflicting views among stakeholders and find ways to resolve the conflict. It can also show the real level at which conflict usually occurs. In model testing, the FRT will be applied to visually unfold the cause and effect relationship between changes we make to the existing systems and their resulting outcomes. During policy design and evaluation phase, the PT will be used to identify obstacles preventing achievement of a desired course of action. Finally, the TT will be used to support strategy implementation by providing a step-by-step method for implementation.

CONCLUSION AND FUTURE RESEARCH

This study is currently in a preliminary stage and thus much more work is needed before constructing the computer simulation model. Causal loop diagrams for each sector in Figure 2 must be developed to become the basis for model development. Next, model assumptions underlying the development of the model must be detailed for each sector. Finally, once the initial model is built up, experimentation and analysis will be performed. Analysis from the model is hoped to help determining the effective intervention for ED capacity planning and capture the concept of system improvement as espoused in TOC.

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