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Patient flow modelling and performance analysis of healthcare delivery processes in hospitals: A review and reflections

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ABSTRACT

Analysis of hospital processes is essential for development of improved methods, policies and decision tools for overall performance improvement of the hospital system. Amidst the current scenario of continuously increasing healthcare costs and scarcity of resources, optimal utilization of resources without hampering the quality of care has gained importance in any country. Modelling, analysis and management of patient flows, in this context, plays a key role in performance analysis and improvement of hospital processes as appropriate modelling of patient flows may help healthcare managers make decisions related to capacity planning, resource allocation and scheduling, appointment scheduling and for making necessary changes in the process of care. The concept of patient flow and its modelling has gained much attention in healthcare management literature over past few decades. In this paper, the existing approaches pertaining to modelling of patient flows in hospital systems have been classified and critically appraised focussing on the recent advancements in order to identify future research avenues. A generic framework for patient flow modelling and performance analysis of hospital systems that may serve as a guide for the practitioners dealing with similar kinds of problems to improve healthcare delivery has also been provided.

1. Introduction

Of late, the study and analysis of any healthcare system has become a necessity for its improved performance over time for which it has to meet a number of, often conflicting, objectives and goals, such as minimizing the cost of healthcare, maximizing the utilization of physical and human resources, improving the quality of care by providing efficient diagnostic systems, handling increasing number of patients effectively within a limited time span, arranging varieties of healthcare facilities in a single location, and improving overall healthcare system performance within limited and predetermined budget and time. Increasing cost of operations and maintenance, and healthcare cost to the patients due to the use of newer technologies, resources and methods have added newer dimensions as constraints to the problems of healthcare system (Brailsford & Vissers, 2011; Brandeau, Sainfort, & Pierskalla, 2004; Rais & Viana, 2010). The objectives of a healthcare system as mentioned above may be achieved effectively with establishment of appropriate healthcare planning and organization along with application of Operations Research – based approaches and other quantitative techniques (Brailsford & Vissers, 2011; Rais & Viana, 2010).

Out of the many subsystems of a healthcare system, hospitals are highly integrated service units attending to the needs of the patients under treatment. A typical hospital system consists of a number of interacting departments/sub-units (Outpatient Department (OPD), department of emergency, inpatient wards, Operating Theatre (OT), Intensive Care Unit (ICU)/Intensive Therapeutic Unit (ITU), diagnostic services, such as Pathology and Radiology, etc.) within a geographical area embedded in an organization. Each department is responsible for a single or at the most, a few related functions within the hospital. Such an integrated system dealing with different aspects of healthcare and its problems may have several possible combinations of service types (hence, varieties of care pathways), patient status, types of facilities as well as physician profiles/specializations available for treatment under varieties of constraints (primarily determined by availability of resources). It is imperative that hospital operational performance is required to be modelled for varieties of care pathways in respect of various system conditions and constraints. The overall performance of a hospital system is dependent on the performance of all the departments/sub-units which have different operational issues, and over

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the years various performance measures, such as waiting time of patient at an emergency department, length of stay of an inpatient, utilization of operating rooms, bed utilization in ICU, etc. to mention a few, have been used to assess the performance of these operations (Cardoen, Demeulemeester, & Belien, 2010; Cayirli & Veral, 2003; Kim, Horwitz, Young, & Buckley, 1999; McClean & Millard, 1998).

An important factor that affects and is a determinant of the performance of healthcare delivery processes in a hospital system is the flow of patients through the system. 'Patient Flow' refers to the 'movement of patients through the whole process of care'. Hall, Belson, Murali, and Dessouky (2006) define patient flow analysis as 'the study of how patients move through the health-care system'. The rate of patient flow entering a system is affected by both seasonal and local factors as well as by the location of hospitals, and the kind of services offered (Alexopoulos, Goldsman, Fontanesi, Kopald, & Wilson, 2008). On the other hand, flow routings through the system are partly dependent on the process of care and decisions taken by physicians, and partly on the inherent uncertainties of healthcare processes (Cote, 2000; Harper, 2002). In this context, there may be two different perspectives for describing the movement of patients through the care process: 'clinical' and 'operational' (Cote, 2000). While patient flow refers to the progression of a patient's health status from a clinical perspective, it represents the movement of patients through various locations (or processes) of a healthcare system from an operational perspective. The flow of a patient through a hospital commences when the patient arrives at the hospital either through the outpatient department (OPD) or through the emergency department (ED) or sometimes admitted to inpatient wards when referred from some other healthcare system. Subsequently, the patient may travel through various routes depending upon the medical condition of the patient, decisions taken by the physicians, the effects of treatment and various constraints of the system. Patient flows are considered to be very complex because of the different pathways patients may take and the inherent uncertainty and variability of healthcare processes (Cote, 2000; Harper, 2002). Moreover, due to limited resource, queues may be formed for various services, and thus the patient flow may be represented by queueing networks (Creemers & Lambrecht, 2011; Hall et al., 2006). Performance of these queueing networks may be analyzed either through analytical queueing formulations, Markov chain analysis or by computer simulation of these networks. A careful and structured analysis of patient flows may reduce the congestions and significantly improve the performance of a hospital system (Hall, 2006; Marshall, Vasilakis, & El-Darzi, 2005; Zhao & Lie, 2008). It is a challenging task for a researcher to capture the inherent random nature and complexities of healthcare elements in patient flow. At various locations of the flow network, there is scope for operational improvements by reducing the delays experienced by patients at the junctions of the phases and also by reducing the idle times of the servers at each phase through effective capacity planning, resource allocation and scheduling and also through appointment scheduling. Another alternative for improving the performance of a healthcare delivery process is through making changes in the process of care. Such changes may include eliminating unnecessary or non-value-adding activities, eliminating duplicate activities, performing some of the activities in parallel, and identifying alternative process flows (McLaughlin & Hays, 2009). Modelling the patient flows may give important insights for such improvements.

Earlier review articles in recent times related to patient flow and performance modelling of healthcare systems in general and hospital systems in particular focus mainly on a single modelling technique, most of which concentrating on simulation technique (e.g., Brailsford, Harper, Patel, & Pitt, 2009; Eldabi, Paul, & Young, 2007; Fone et al., 2003; Green, 2006; Gunal & Pidd, 2010; Jun, Jacobson, & Swisher, 1999; Katsaliaki & Mustafee, 2011; Zonderland & Boucherie, 2012). In this paper, an attempt is made to review the frequently used modelling approaches specific to patient flow and performance analysis of healthcare processes in hospitals with a focus on the recent advancements and to bring out the reflections on the evolution of these techniques and to identify the appropriate modelling and analysis techniques according to the characteristics of patient flow and the type of problem to be solved. Critical appraisal of these techniques identifies key issues to be addressed while carrying out patient flow modelling and performance analysis. A generic framework for carrying out such an analysis is also presented. The remainder of the paper is organized as follows. Section 2 explains components of a patient flow network and its characteristics; Section 3 provides the aspects to be modelled and a review of the recent literature on patient flow modelling; Section 4 presents the performance measures used in the literature to assess the operational performance of various services of a hospital; Section 5 presents a generic framework for performance assessment through patient flow modelling. Concluding remarks are drawn in Section 6.

2. Components of a patient flow network and its characteristics

In the context of patient flow modelling, the aspects related to the building blocks of the patient flow network, the multiphase nature of the flows and the inherent uncertainties and complexities of patient flows need to be discussed before getting into the details of its modelling techniques.

2.1. Elements/building blocks of a patient flow network

As has been stated in the previous section, the flow of patients through a hospital system may be represented as queueing networks, and like any queueing network, elements or building blocks of patient flow networks include the network structure (which consists of an entrance point, an exit point, various single-server or multi-server nodes between these two terminal points, and the paths connecting the nodes), patients (the entities which are flowing through the network), and the resources (both physical and human) which act as servers at the nodes. Depending on whether the patient flow is being considered from a clinical or an operational perspective, the nodes represent either a health state (condition) of a patient (e.g., Xie, Chaussalet, & Millard, 2005) or a location in the hospital or a department (e.g., Cote & Stein, 2007).

2.2. Stages in patient flow

Any kind of patient flow, clinical or operational, through any type of process of care in a hospital, whether it is outpatient care, emergency care, surgical care or inpatient care, may, in general be considered as a multistage/multiphase process (Hulshof, Kortbeek, Boucherie, Hans, & Bakker, 2012). If the flow is being considered from an operational perspective, the stages represent various processes, such as registration, consultation and examinations (e.g., blood tests and X-ray). On the other hand, if the flow is being considered from a clinical perspective, the stages represent different stages of patient's health status. For instance, a patient admitted in a geriatric department may have health states like acute condition, condition requiring rehabilitative care and that requiring long stay (McClean & Millard, 1998). A particular patient may not need to undergo all the defined stages in a care process or a care pathway. Typical activities at each phase include arrival, wait, treatment/service, and leave/exit. The simplest of patient flows