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Hospital Event Simulation Model: Arrivals to Discharge–Design, development and application

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ABSTRACT

In this paper we outline the design, development and application of a hospital patient flow management support tool – Hospital Event Simulation Model: Arrivals to Discharge (HESMAD). The model captures the patterns of patient flows within Flinders Medical Centre, a teaching hospital located in South Australia, through extensive exploitation of an existing hospital patient journey database (PJD). HESMAD employs mathematical and statistical modelling techniques, as well as the concept of modular design, to construct functions and processes that are embedded in a discrete event simulation system. The current structure of HESMAD reflects many iterations of refinements based on feedback from relevant industry experts. It places great emphasis on providing an engaging visualisation of the dynamics of events, and a convenient interface for domain experts: doctors, hospital managers and other health care professionals. An illustrative example of HESMAD's wider applicability is presented.

1. Introduction

Australian public hospitals operate under strict resource constraints and are facing new challenges due to increasing patient demand and budget cuts. Arguably, this has been manifested by higher incidence of ambulance ramping and more frequent occurrence of patient flow congestion episodes accompanied by longer waiting times and other adverse effects, which, in turn, have led to an increase in public complaints and, possibly, sub-optimal health outcomes for patients. With hospitals now expected to operate at, or close to, full capacity much of the time, gone are the days of spare capacity, namely, some empty beds, which can be utilised during peak demand periods. Consequently, there is a well-recognised need to make best use of all available information and domain knowledge to ensure that hospital resources and expertise are utilised more efficiently, for the benefit of all stakeholders.

The latter is no simple task since hospital operations involve complex interactions among many groups of health professionals utilising limited physical facilities and human resources. This is further complicated by the inherent variability of patient responses to treatments. Indeed, the stochastic nature of the demand process, as well as uncertainty in durations of medical treatments and patient recovery, inevitably lead to probabilistically distributed bed availability. Recent studies have started to address these concerns. However, it has been noted that simple generalisations such as fixed and safe operating

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levels or simply shortening patient–doctor face time will do little to actually address the congestion within the hospital [1–4]. More specific studies and actions are necessary to understand the root causes and thereby deal with the aforementioned problems. One could further argue that, in terms of addressing congestion within a particular institution, such studies would need to be tailored. Fortunately, Australian hospitals are "data rich", that is, reliable records of patient journeys have been kept for many years. While older data may reflect procedures and priorities that are no longer in practice, data from recent years can be regarded as quite robust, especially in cities/regions that have not experienced major demographic changes. The availability of such data presents an opportunity for the use of modern mathematical, statistical and simulation modelling tools that could enhance our understanding of key processes and their interactions that influence a hospital's operations. The understanding so obtained can then be used to assist hospital staff in devising operational procedures that are likely to minimise disruption without adversely impacting the service quality provided to the patient population.

Flinders Medical Centre (FMC), an urban teaching hospital of about 500+ beds in southern Adelaide, has been a world leader since 2002 in using Lean Thinking in the hospital context as an improvement methodology to remove inefficiencies that lower the quality of patients care. That program has enabled the hospital to provide safer and more accessible care [5,6]. However, it has also been recognised that, in order to take the improvement to a higher level, detailed quantitative modelling of the dynamic behaviour of the hospital system based on information extracted from a very rich, but complex, patient journey database (PJD) is needed.

In order to address this need, we developed Hospital Event Simulation Model: Arrivals to Discharge (HESMAD) to capture the dynamics of patient flows within FMC. The main purpose of HESMAD is to provide a macro level overview of the hospital system in which the interactions between the various core components (physical units and process modules) of the hospital can be investigated. Patients go through a set of physical units and process modules that model various physical areas, processes, interactions and behaviours within the hospital to replicate a wide spectrum of patient journeys. The design details of HESMAD involved extensive consultation with colleagues from the hospital. For example, patients within HESMAD are not modelled as identical entities, rather, they are assigned different attribute values, in relation to both personal characteristics and organisational attributes, such as mode of arrival, triage category and division to reflect the typical profile of all patients observed from historical data. Hospital and patient data from 2012 to 2013 were used to fit various probability distributions, such as the waiting times for treatment or discharges. The model allows for a realistic representation of patient flows, at a level of resolution that was deemed appropriate, by the hospitals data management experts, for balancing complexity and fidelity. The model has been validated against historical data and through consultation with health care and hospital experts. Currently, HESMAD is being used to test hypotheses about main causes of congestion episodes, identify precursors that flag the possible onset of these episodes, and compare the effectiveness of proactive operational interventions intended to mitigate against disruptions due to unanticipated increases in demand.

We do note that simulation and more specifically discrete event simulation has a long history within the health care modelling field. There has been a considerable amount of research effort spent on simulating specific aspects of health care and the hospital systems, particularly the emergency department [7–12]. The growth in this field is well represented within the literature through the increased number of papers published on operations research modelling over the last 30 years [13]. Most attention has been directed to modelling the impact of variations to staffing levels, rosters and resource usage. Some works that seek to understand the interplay between the various hospital sections and ED have invoked queuing systems approaches [14,15]. However such approaches make assumptions about the nature of the queuing (e.g., memoryless) which can obscure the extreme cases. It has been noted in [16] that much of the work to date has not been sufficiently generalisable to allow for application and implementation outside of the actual specific case it was developed for. Another issue has to do with useability and support of the simulation in the health care sector. Unlike that in manufacture and business sectors, undesirable usability and lack of support seem to have hampered the adoption of simulation as a decision support tool for health care managers. The recent calls for better understanding of the interactions between ED and the rest of the hospital has encouraged more holistic simulation development [17,18]. Finally, it should be noted that simulation is but one tool (albeit a highly useful tool) in modelling the hospital system. Other forms of modelling, together with expert insight and consultation, should also be considered to supplement our understanding.

The rest of this paper provides a systematic overview of HESMAD. Section 2 is dedicated to a detailed discussion of HESMADs structure, underlying balance equation, features, capabilities, and design and development decisions, including descriptions of how each of the process modules is constructed and its various underlying distributions extracted using the PJD. Section 3 addresses validation of HESMAD. Finally, in Section 4, we provide a brief case study demonstrating the potential applicability of HESMAD for 'what if' analyses of hospital interventions.

As a final note, while HESMAD is demonstrated for the Flinders Medical Centre, the methodology as described may be generic enough for applications to other public hospitals in Australia. In fact a key consideration behind HESMADs macro level modular design was to make the platform sufficiently generalisable to allow applications to other institutions with the possibility of carrying out comparisons. The data with which a particular variant of HESMAD is built should be readily available at most hospitals therefore extra data collection would not be required. However, additional data ultimately could be used to further supplement HESMADs design thereby improving its reliability, validity and robustness.