MODELLING THE ACUTE HEALTH SYSTEM: PATIENT FLOW ANALYSIS FOR IMPROVED HEALTH SERVICE DELIVERY

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ABSTRACT
Routine collection of health care information by government agencies provides a wealth of potential for improving the delivery of healthcare through the analysis of patient flow. We describe our work in secondary analysis (i.e. differing from the purpose originally intended) of hospital information datasets comprising episodes of patient care. Our patient flow tools and analyses have application to public health agencies striving to improve the productivity and efficiency of service delivery, where evidence-driven strategies are desired to support improved health outcomes.

KEY WORDS
Health care information systems, data representation and visualization, patient flow

1. Introduction
The focus for our group in patient flow modelling within the health system is to improve hospital capacity management and access to beds and reduce hospital crowding. Overcrowding in hospitals has been labelled an “international crisis”, and significantly impacts the quality of care delivered and the quality of the patient experience. The focus of much recent government policy has been on optimal and timely resource management, which is key to the successful operational management of modern hospital systems.

Most acute public hospitals are plagued by slow throughput times, long perceived waiting periods, limited surge capacity, technology integration challenges, efficiency bottlenecks, antiquated treatment spaces, lack of proper integration with community, and response to catastrophic events. Hospital executives and department directors are balancing a range of competing priorities on a daily basis including increased patient acuity, staffing shortages, delayed throughput, system bottlenecks, advances in technology and data management systems, emergency preparedness and facility maintenance.

Capacity management practices vary widely between hospitals, and guidelines informing how to manage inpatient bed occupancy efficiently are limited. It is difficult to inform these strategies without system evaluation. Experts [1] advocate that while investments in capital and workforce are important to improving capacity, the greatest efficiencies in patient management are going to be found in system evaluation and redesign. Meeting targets relating to flow performance is not solely the responsibility of emergency or surgery departments, and instead, whole-of-hospital engagement is essential in ensuring obstacles to effective patient flow are removed.

Supporting acute hospitals through individualised patient flow modelling presents an opportunity to apply evidence-driven strategies to support improved health outcomes, on the premise that knowledge equals productivity. A better understanding of flow bottlenecks, and optimised bed numbers for patient specialty groups can improve capacity management strategies and care outcomes.

This paper describes patient flow tools and analyses we have developed in collaboration with our partner hospitals (who provide operational and clinical leadership) and universities (who have enhanced the statistical data analyses with qualitative assessment on work practice improvements). Examples are provided of projects that have shown to result in improvements to the delivery of acute healthcare with a common theme of hospital capacity management and patient flow.

2. Patient Flow Analyses
Our modelling of patient flow is based on retrospective analysis of hospital in-patient and Emergency Department (ED) data from reporting public hospitals in Australia, across time-spans of up to 10 years. In many of the analyses, we explore relationships between patient flow measures by first aggregating patient episode data into hourly time intervals [2].

Our belief is that daily measurement of patient flow parameters may be good for general planning tasks, but an hourly measurement frequency is more accurate for the critical task of managing patient flow in crowded hospitals.

Our capabilities in patient flow analysis are depicted in Figure 1, which shows a number of modelling activities based on ED data, in-patient data, and the linking of ED and ambulance data.
2.1 Linking of ED and ambulance data

An important element of patient flow is pre-hospital care delivered by ambulance services. However often ambulance services maintain separate databases to hospital admissions data and identify patients in different ways. Privacy can also be an issue, with legislative requirements restricting the sharing and storage of information and use of unique patient identifiers. Our centre has developed a mechanism to deal with these issues through a data integration tool [3]. This involves novel privacy preserving linkage between datasets where data stays with the data custodians (no warehousing). The resulting tool allows easy data interrogation, reporting and analysis to enable population and evidence-based research to be undertaken.

A comparison of this automated deterministic linking with manual linking was undertaken in a large regional teaching hospital ED over a 2-month period involving 3469 ambulance records, 10835 ED records, and 3431 hospital admission records. With manual linking, ED records were linked with 92% of ambulance records and 94.5% of the hospital admission records. With automated linking, ED records were linked to 88% of the ambulance records and 95% of the hospital admission records [4].

The tool has been used to link patient data from the state’s ambulance service with emergency department and hospital admission data to give a complete view of patients’ journeys from arrival in the ambulance through to discharge [5]. This gave a detailed view of hospital workload before and after the opening of a new hospital emergency department (with no extra hospital beds). Such projects are crucial in setting expectations for building new EDs and the flow on effect to hospital admissions, and patient well being.

2.2 Disease surveillance

Disease surveillance is another important information component in health service delivery, enabling patients to receive targeted support to better manage their health if hospitalisation is required. This public health research encompasses disease surveillance and outbreak/anomaly detection and epidemiology.

These measures can inform and shape appropriate response policy for state health departments. For example, a new strain of influenza might result in increase ED presentations but affect a particular age group more dramatically, or an increase in gastrointestinal illness may be reported in a particular area. Early detection of such events would enable public health officials to prepare resources, public health awareness campaigns or begin determining disease sources as quickly as possible.

We have undertaken surveillance activities focusing on influenza, as outbreaks of this occur annually causing considerable burden on hospitals each winter. We studied the incidence, characteristics and outcomes of patients with influenza-like symptoms presenting to 27 public hospital EDs in Queensland, Australia over five years [6] and also used surveillance and forecasting models to predict and track epidemics of influenza [7]. Models assessed include surveillance monitoring of influenza ED presentations using adaptive cumulative sum (CUSUM)
plan analysis to signal unusual activity, generating forecasts of expected numbers of presentations for influenza, based on historical data, and using internet search data as outbreak notification among a population. These methods are considered applicable to all health facilities that routinely collect and code patient arrival data. The best system among those assessed was a combination of routine forecasting methods coupled with an adaptive CUSUM method. The analysis highlighted the value of health departments performing surveillance monitoring to forewarn of disease outbreaks.

2.3 ED Length of Stay (LOS) performance

Timeliness of care is an important performance metric for all health agencies. Many countries have implemented policies designed to improve ED bed access times. For example, in Australia in 2012, a new National Emergency Access Target was implemented, where 90% of all patients presenting to a public hospital ED are to either physically leave the ED for admission to hospital, be referred to another hospital for treatment, or be discharged within four hours [1]. The UK’s NHS introduced new clinical quality indicators in 2011 to replace a similar four hour A&E operational standard, and timeliness represents a large component of these indicators (eg. total time spent in the A&E department, percentage of people who leave the A&E department without being seen, time to initial assessment, time to treatment). The American College of Emergency Physicians has also recently indicated they support the introduction of a four hour timeframe.

We have undertaken reviews of historical ED LOS performance for a major tertiary hospital in Victoria, Australia across 7 years. The analysis covered performance by unit and specialty and investigated other factors that influence ED LOS performance such as patient arrival rates and patient case-mix. This work found a significant difference in performance between those patients who were admitted following their presentation and those who weren’t, and strong differences amongst specialties and units. One of the more striking factors influencing ED LOS was the time of day at which the patient arrived. We have extended this work by assessing the impact of arrival time and in-patient occupancy on ED LOS based on 27 major reporting facilities in Queensland.

2.4 Bed prediction

The hospital performance benchmarks mentioned above rely on the ability of hospital staff to get a patient to the right bed at the right time, and this in turn relies on knowledge of bed demand. The application of predictive technology to forecast patient demand can support bed planning activities leading to improved hospital performance and transparency.

Our team have developed, validated and implemented models to predict ED presentations and subsequent hospital admissions and discharges for time and day of the year [8-10]. Initial model development and validation was based on 5 years of historical data from two dissimilar hospitals, followed by subsequent validation on 27 hospitals representing 95% of the ED presentations across the state. Forecast accuracy was assessed using the mean average percentage error (MAPE) between forecasts and observed data (daily MAPE ~ 11%).

The conclusions from this work are that presentations to the ED and subsequent admissions to hospital beds are not random and can be predicted. We have also developed a User Experience Base through a detailed consultation process with ED and bed management planning staff to identify user expectations and functional requirements [11]. The consultations identified that bed prediction systems should be incorporated with existing systems; models should be validated; the data fields adequately defined; and the time periods to be forecast to be at a useful resolution for bed managers. We are currently implementing process redesign as a result of this new information [12] (bed manager behaviour changes) and assessing patient flow outcomes following implementation.

2.5 Patient flow visualisation

Despite the collection of large amounts of rich patient flow data, many health workers have limited tools to effectively interrogate this data. This issue isn’t unique to the health sector, with industry and government bodies having the capability to collect data but limited ability or resources available for analysis [13]. Visual analytics enables users to understand complex trends embedded in large datasets which directly supports planning and decision making, providing an effective means for patient flow analysis.

We have create a user-friendly support tool for bed administrators to aid decision making through viewing and analysing routinely collected hospital data [14]. A Graphical User Interface with a variable time-span viewing window allows a user to view in-patient and ED data trends over a day, week, month and a year. To avoid excessive noise when displaying long time periods, data is aggregated into daily and weekly time intervals. Patient flow parameters include occupancy, ED and in-patient arrival and discharge rates (patients per hour/day/week etc) and lengths of stay, which can be filtered by all available fields in the data (eg. by age, elective status, primary diagnosis etc).

The functionality provided by such patient flow tools which distill routinely collected hospital data into useful information can form an important component in the arsenal available to hospital bed managers for their daily decision making.
2.6 Patient flow as a function of occupancy

Targets related to revenue and patient access performance contribute to pressures on hospitals to maximize the utilization of beds. The optimum occupancy level of acute hospitals is a topic of much controversy. It is anticipated that patient flow is affected as in-patient occupancy levels increase, although a widely cited target of 85% has been criticised as being inappropriate [15] and too generalised [16] to be useful.

We sought to contribute evidence around increasing the knowledge of acute hospital capacity management and in-patient bed requirements to meet community demands. This work investigated the effect of hospital occupancy levels on in-patient and ED patient flow parameters through retrospective analysis of hospital in-patient data and ED data from 23 reporting public hospitals in Queensland, Australia, across 30 months [17]. The study identified three stages of system performance decline, or choke points, as hospital occupancy increased. These choke points were found to be dependent on hospital size, and reflected a system change from ‘business-as-usual’ to ‘crisis’. The conclusion from this work was that modern hospital systems have the ability to operate efficiently above an often-prescribed 85% occupancy level, with optimal levels varying across hospitals of different size. Operating over these optimal levels leads to performance deterioration defined around occupancy choke points. Understanding these choke points and designing strategies around alleviating these flow bottlenecks can improve capacity management, reduce overcrowding and improve patient outcomes.

2.7 Configuration of beds

In many hospitals, the way that beds are assigned to specialty units and wards is a static allocation that follows historic practices, and not optimised with regards to flow performance. For example, the cardiac speciality unit may be allocated 8 beds in one wing of the hospital, the paediatric unit might have 12 beds in another wing, and this configuration applies all times of year. Demand pressures can change but often units have not had their bed allocations reviewed. Further, if additional bed capacity becomes available, allocation should be in a way that maximises flow performance. Patients need to be placed in a bed in a timely manner requiring access to the right bed at the right time. Delays in access to the bed most suited to the patient’s requirements leads to poorer care and excessive hand offs and bed moves. Having the right mix of beds is critical to achieving efficient service delivery.

Our team have developed simulation models, for patients admitted to in-patient beds from ED, to assess how changing the numbers of beds in different speciality groups affects the waiting times for in-patient beds. In particular, the models have been used to count the percentages of patients discharged in four hours or less from the ED to an in-patient speciality bed. An optimisation module adjusts the number of beds in the specialities to find the minimum number of beds needed to achieve a specified ED LOS, for example, that 90% of patients are admitted in less than four hours. We have also used the model to investigate the performance of the system when common sets of beds are shared by different specialities, and quantified those improvements. For example, a cluster might contain the Cardiology, Cardiac Surgery, Respiratory & Sleep Medicine, and Thoracic Surgery specialities, and sharing these resources together results in improved bed utilisation. Infection control is also an important consideration in dynamic allocations and determining appropriate clustering.

2.8 Adverse event analysis

A balancing argument in the face of pressures to fill hospitals to capacity to improve bed utilisation is that the safety of patients may be compromised through increased staff workload and stress. There is much supposition and guesswork in understanding how hospital occupancy relates to patient safety and the evidence that higher in-patient occupancy equates to a higher likelihood of adverse events is minimal.

The team have explored this important issue through examining the relationship between daily hospital occupancy rates and the occurrence of reported adverse events. The study across 12 months of historical data from a large quaternary metropolitan hospital in Australia focused on preventable adverse events: medication administration, falls, and clinical management (as opposed to events such as post-operative acute myocardial infarction, wound sepsis, or hospital-acquired pneumonia). Hospital records of midnight occupancy and reported safety incidents were matched by date, identifying the nature and number of adverse events reported against occupancy level. The conclusion from this work was that increased hospital occupancy increases the reported incident rate and probabilities of adverse events occurring, which can inform capacity management strategies in public hospitals.

2.9 Early discharge strategies

A typical pattern for many hospitals is that the rate of patient arrival peaks earlier in the day than the rate of patients discharged from hospital. Consequently a widely recommended strategy for improving patient flow in acute hospitals is to bring the time of patient discharge earlier in the day. In the face of little evidence to support this, some clinicians have questioned whether such strategies
make a difference to patient flow and in-patient occupancy.

Our team have analysed the impact of in-patient discharge timing on ED length of stay, while comparing this to the effect on hospital occupancy, to arrive at an understanding of a ‘whole of hospital’ response to discharge timing [18,19]. By studying 30 months of historic data across 23 hospitals, the team identified that hospitals of all sizes exhibit increased levels of occupancy and in-patient and ED length of stay on days when the discharge peak lags (occurs after) the peak in in-patient admissions. To counter the effects of day-of-week effects, we also simulated the impact of shifting all discharges earlier or later on occupancy levels. The conclusion from this work was that effecting early discharge of patients significantly impacts overcrowding levels and improves patient flow, and discharging patients only one hour earlier makes a difference.

2.10 Readmission prediction

Improving the management of high cost patients, especially those with long term conditions, is increasingly seen as an important strategy for improving health outcomes and controlling healthcare expenditure [20]. The World Health Organisation (WHO) describes care for long term conditions as “the health care challenge of this century”, with such conditions currently responsible for 60 per cent of the global burden of disease and likely to be the leading causes of disability by 2020. Research has shown that a minority of “frequent flyer” patients account for a disproportionately large proportion of health expenditure. This situation may become more pronounced as people are living longer with increasingly complex conditions and as the actual number of people with a long term condition increases.

This work is about putting in place so-called ‘upstream’ care to prevent the deterioration of individuals’ conditions to the point where an expensive acute emergency admission is required.

Our work in predicting the risk of hospital readmission involves developing a mechanism to “flag” chronic disease patients who have a high probability of subsequent emergency admissions so a care team can provide targeted interventions. We have started with a lower socio-economic urban area, with an initial focus on chronic disease patients, and have worked through large challenges relating to data from many data sources: ED, in-patient, outpatient, community health, pharmacy. Our best model to predict risk of readmission of chronic disease patients has an area under the Receiver Operating Characteristic curve of 64% (random 25% evaluation datasets across 10 years). We are attempting to improve on this by learning of patient visits to hospitals outside the catchment area.

3. Conclusion

Many health agencies are being 'overwhelmed' by rising health costs, and without productivity improvements, i.e. doing more with fewer resources, the ability of these providers to offer the services they currently provide will be significantly strained.

The examples presented in this paper demonstrate the potential of modelling to improve health outcomes through improved productivity and utilisation of acute hospital beds. Such analyses can contribute substantially to the formation of evidence driven strategies and policy achievement.

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