Evaluating the effects of increasing surgical volume on emergency department patient access

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Aim: To determine how increases in surgical patient volume will affect emergency department (ED) access to inpatient cardiac services. To compare how strategies to increase cardiology inpatient throughput can either accommodate increases in surgical volume or improve ED patient access.

Methods: A stochastic discrete event simulation was created to model patient flow through a cardiology inpatient system within a US, urban, academic hospital. The simulation used survival analysis to examine the relationship between anticipated increases in surgical volume and ED patient boarding time (ie, time interval from cardiology admission request to inpatient bed placement).

Results: ED patients boarded for a telemetry and cardiovascular intensive care unit (CVICU) bed had a mean boarding time of 5.3 (median 3.1, interquartile range 1.5–6.9) h and 2.7 (median 1.7, interquartile range 0.8–3.0) h, respectively. Each 10% incremental increase in surgical volume resulted in a 37 and 33 min increase in mean boarding time to the telemetry unit and CVICU, respectively. Strategies to increase cardiology inpatient throughput by increasing capacity and decreasing length of stay for specific inpatients was compared. Increasing cardiology capacity by one telemetry and CVICU bed or decreasing length of stay by 1 h resulted in a 7–9 min decrease in average boarding time or an 11–19% increase in surgical patient volume accommodation.

Conclusions: Simulating competition dynamics for hospital admissions provides prospective planning (ie, decision making) information and demonstrates how interventions to increase inpatient throughput will have a much greater effect on higher priority surgical admissions compared with ED admissions.

Competition for hospital-based healthcare services has increased in recent years because of countervailing trends in demand and supply. US hospital admissions have increased by 13% and emergency department (ED) visits have increased by 26% between 1993 and 2003. Over this same period, financial pressures have resulted in the loss of 703 hospitals, 198 000 hospital beds and 425 hospital-based EDs.[1] All patients are not economically equal in the US commercialised healthcare system. Hospitals face financial pressure to provide specific services and are often motivated to allocate resources in response to profit opportunities rather than medical need.[2] Profit centres and sinks have emerged in hospitals and management practices based on priority structures are in place. From a financial standpoint, the operating room (OR) and the emergency room fall on opposite ends of the spectrum. Electively scheduled surgical patients typically generate the most revenue, while naturally arriving ED patients generate the least and are often cared for at a net loss.[1]

The two most common sources of inpatient admissions are from the OR (eg, 35%) and the ED (eg, 50%).[1] ED and surgical patients constantly compete for inpatient resources.[3 4] Financial incentives to improve surgical patient access include the following: (1) surgical patients generate better margins; (2) elective surgeries must be cancelled or delayed if postoperative inpatient beds are unavailable; (3) if service is poor, elective patients can be treated at other hospitals; and (4) efficient perioperative management of surgical patients promotes loyalty among revenue-generating surgeons.[1] There are few financial incentives to improve ED patient access. This has resulted in a severe bottleneck at the ED–hospital interface delaying treatment, causing conditions of crowding and degrading quality of emergency care.[1 5–9]

ED BOARDING

When inpatient beds are unavailable, admitted patients wait (ie, board) in the ED, occupying space and consuming resources until an inpatient bed is available. Boarding

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time is defined as the time interval from hospital admission request to the time the patient is transferred to an inpatient bed. Boarding is common in US EDs. Out of 2000 hospitals surveyed, 90% boarded patients at least 2 h and 20% averaged an 8 h boarding time.[9] Boarding is the most significant contributor to the crowding crisis that plagues EDs nationwide.[1 5–9] Two government-sanctioned reports suitably titled “Bursting at the Seams” and “At the Breaking Point” describe the threat to quality and safety that boarding and resulting crowding have placed on the emergency care system.[1 8] Cardiac and critically ill patients examined in this study are particularly vulnerable in crowded emergency care settings.[10–15] Consequently, the Institute of Medicine has mandated that hospitals end the practice of boarding patients except in the most extreme circumstances.[1] Hospitals across the USA must strive to minimise boarding time for all ED-admitted patients despite the financial disincentives.

OBJECTIVE

The study hospital is constructing new surgical facilities scheduled to open within 5 years, resulting in substantial increases in projected surgical volume. A stochastic discrete-event simulation was created to determine how projected increases in surgical volume will affect ED patient access to inpatient cardiac services. The specific goals of the simulation were to (1) quantify the effects of increases in surgical volume on cardiac patients' boarding time in the ED, (2) inform cardiology inpatient capacity expansion plans, if necessary, and (3) examine how decreasing inpatient length of stay (LOS) can free capacity to improve ED patient access or accommodate new surgical volume. The simulation was designed to aid cardiology administrators' decision making in light of these upcoming changes.

METHODS

Setting

The study was performed at a US, urban, academic, tertiary care hospital with a 45-bed ED and a 73-bed cardiology division consisting of 47 telemetry beds and 26 cardiovascular intensive care unit (CVICU) beds. The division of cardiology (telemetry and CVICU) functions within the cardiology macrosystem, seen on the right side of figure 1.[16] Patients flow between the ED, OR, post-anaesthesia care unit, cardiac catheterisation laboratory (CATH LAB), cardiology inpatient beds, other hospital units and home.

Design

This was a retrospective cohort study that included all patients who entered the cardiology macrosystem over a 1-year period from May 2006 to May 2007. ED and surgical patients admitted by cardiology to a telemetry or CVICU bed were the focus of the study. Demographic and clinical data were collected from multiple information systems and merged to construct patient flow times and patterns for each patient in the study cohort.

Modelling boarding time

Survival analysis was used to construct a Cox proportional hazard regression model to predict expected boarding time for patients admitted to a cardiac telemetry or CVICU bed.[17] Separate hazard models were

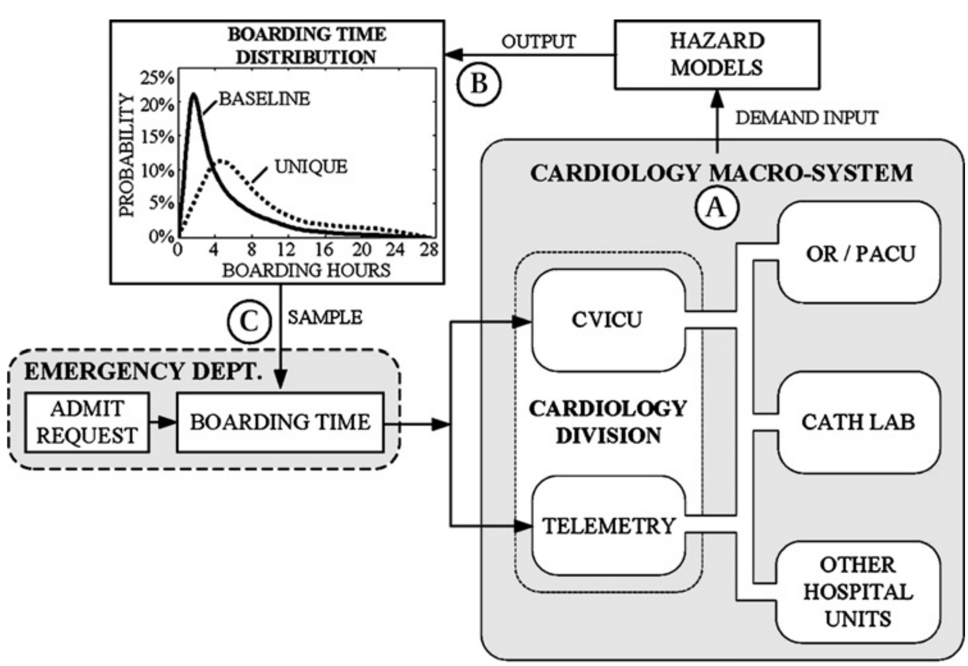

Figure 1 Discrete event simulation using survival models. CVICV, cardiovascular intensive care unit; OR/PACU, operating rooms and post-anaesthesia care unit; CATH LAB, cardiac catheterisation laboratory. (A) Demand measurements collected from cardiology macrosystem and input to hazard model. (B) Hazard model outputs a unique probability distribution of expected boarding time. (C) Time interval is sampled from distribution and assigned to patient as boarding time.

created for patients boarded for the telemetry unit and CVICU. Boarding time (ie, "survival" in the model) was defined as the time interval between hospital admission order and the time the patient was transferred to an inpatient bed. Operational, demographic and clinical covariates hypothesised to influence ED boarding time (ie, dependent variable) were considered. Operational covariates designed to measure the level of demand from competing telemetry and CVICU admission sources were collected at the instant an ED physician placed the admission request. The proportion of patients admitted to cardiology from competing admission sources is shown in figure 2. Operational (ie, demand) measurements from competing admission sources were collected from clinical information systems for each ED patient admitted to either a telemetry or CVICU bed. ED operational measures such as ED occupancy and number of boarded patients were included. Independent variables measuring hospital demand were scaled to 1. Patient demographics included in the pool of potential covariates were age and sex. Patient clinical covariates included medical history, cardiac interventions in the ED and Thrombolysis in Myocardial Infarction Risk Score.[18] Medical history variables were prior myocardial infarction, cardiomyopathy, coronary artery disease, congestive heart failure, hypertension, hyperlipidaemia, diabetes mellitus, tobacco use and family history of coronary artery disease. Examples of ED-based cardiac intervention were nitroglycerin, aspirin, clopidogrel, beta-blockers, heparin, glycoprotein 2b/3a inhibitors, enoxaparin and ACE inhibitors.

Model variables that captured demand from competing cardiology admission sources were deemed most important based on the strength of their coefficients and statistical significance. All demographic, ED and clinical variables were eventually excluded because they did not significantly affect the model. The insignificance of clinical variables may be a result of the controlled patient populations (ie, ED patients admitted to specific beds) examined in the models.[13] The independent variables used to predict ED boarding time measured demand in the following units: telemetry, CVICU, other, OR and CATH LAB. A description of how demand in each of these units was measured may be seen in appendix table AI, available online only. The telemetry and CVICU boarding time hazard models may be seen in appendix tables AII and AIII, available online only along with additional descriptions. The reader is referred to prior published work for further details on the boarding prediction methodology.[13 17]

Patient flow simulation using survival models

The discrete-event simulation of patient flow through the cardiology macrosystem was created using MATLAB (Mathworks, Natick, Massachusetts, USA) and MedModel (Promodel Corporation, Orem, Utah, USA) simulation software. The process of creating the simulation started with modelling boarding time using survival analysis as outlined above. The simulation model was designed to include all demand variables (see appendix table AI) determined to effect ED boarding time for cardiology patients. Patient flow,

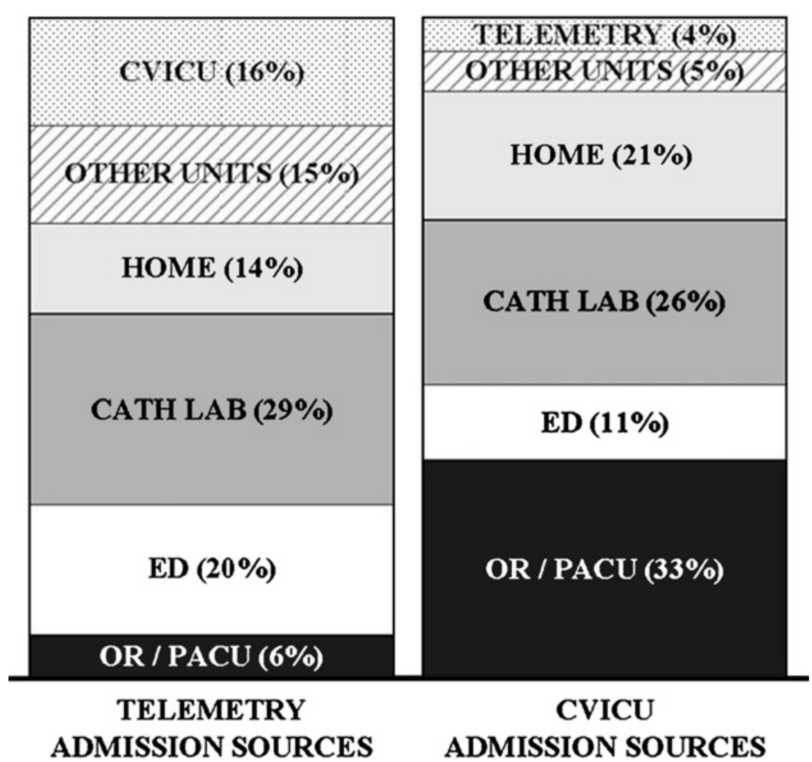

Figure 2 Competing cardiology inpatient admission sources. CVICV, cardiovascular intensive care unit; OR/PACV, operating room and post-anaesthesia care unit; CATH LAB, cardiac catheterisation laboratory.

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characterised by patient arrival times, LOS and transfer patterns was reconstructed from time-stamped patient event information collected over the 1-year study period. This information was converted to time-dependent distributions that probabilistically determined the timing of discrete events (ie, patient flow) in the simulation. All patient flow events (ie, arrivals, transfers and discharges) for the locations depicted in figure 1 are modelled in this fashion except for ED boarding time to cardiology division units. The hazard models used to predict boarding time for telemetry and CVICU patients were embedded within the simulation model. Specifically, the hazard models were programmed into the simulation as functions to predict boarding times for CVICU and telemetry bound patients in the ED. A conceptual model of the simulation can be seen in figure 1. A snapshot of demand was captured from each of the simulated cardiology macrosystem locations at the instant a cardiology admission request was placed for a simulated ED patient. Demand measurements were input to the appropriate hazard model (step A in figure 1) for each cardiology-admitted patient. The hazard model outputted a unique probability distribution of boarding time (step B). A sample was drawn (step C) from the unique probability distribution that defined boarding time. This process was repeated for each ED patient admitted to cardiology.

Logic-directing simulated patient flow used queuing principles based on a framework that classified each location modelled. Telemetry and CVICU units were modelled as reactive; these units reacted to time-dependent fluctuations in demand coming from all inflow sources. The OR and CATH LAB were modelled as proactive; these high-priority units directed patient flow with highest priority to and from other locations in the model. The ED was treated solely as an input source to all other locations. Thus, simulated patients were not permitted to transfer from a cardiology macrosystem location to the ED, consistent with the real system. It is important to note that all ED patients were simulated, not just cardiology patients. Simulated ED patients could be discharged home, admitted to another hospital unit (ie, figure 1, other hospital units), transferred to the CATH LAB or OR, or admitted directly to a cardiology unit. Only discharged patients exited the model from the ED. Other hospital units were modelled as a single input/output source to reflect the cross-service sharing of beds that exists between cardiology and the rest of the hospital.[13] Transfer probabilities that directed patients from one location to the next were calculated from actual hospital data. A patient's transfer probability to each potential future location was dependent on the patient's previous location. Implementing this logic within the model preserved common patient flow pathways (eg, OR to CVICU to telemetry to discharge home) that exist within the real hospital.

Simulation verification and validation

The simulation was probabilistically driven by actual distributions collected from multiple information systems. Distributions capturing the number of arrivals and LOS (excluding boarding time) were simulation inputs. Arrival rate distributions were aggregated by day of week and hour of day. Arrival (ie, admissions) and LOS distributions were examined and compared for each month to determine if any long-term trends would improve the accuracy of the model. It was determined that the system was operating with significant daily variability but in steady state month to month. Thus, no monthly trends were incorporated into the simulation model. OR and CATH LAB schedules were direct inputs to the model. Simulation LOS at a location was defined as the time interval from when a patient entered a unit from any location to when the patient exited that unit to any other location or home. These distributions were verified for each location by comparing measurements of central tendency (ie, median) and variability (ie, interquartile range) for the simulated versus real system as seen in appendix table AIV, available online only.[13] In addition, Mann–Whitney U tests were used to confirm that these corresponding measures (real vs simulated) may have been drawn from the same population and therefore the distributions may be considered equal.

Boarding time to the telemetry unit and CVICU, location census distributions and temporal patterns were the major output variables validated against the real system. A comparison of boarding time distributions for the simulated and real system is displayed in figure 3. Boarding time and census distributions were similarly validated by comparing measurements of central tendency (ie, median) and variability (ie, interquartile range) for the simulated versus real system as seen in appendix table AIV. Mann–Whitney U tests were used to confirm that these corresponding measures (real vs simulated) may be considered equal. In addition, Pearson correlation coefficients were calculated to measure that the weekly temporal pattern in patient census for each location adequately matched the real system. Validation of these measures is displayed in the Length of Stay and Census Distribution sections of table 4 (online appendix table AIV).[13]

RESULTS

The division of cardiology received 10 881 separate visits during the 1-year study period. The telemetry unit

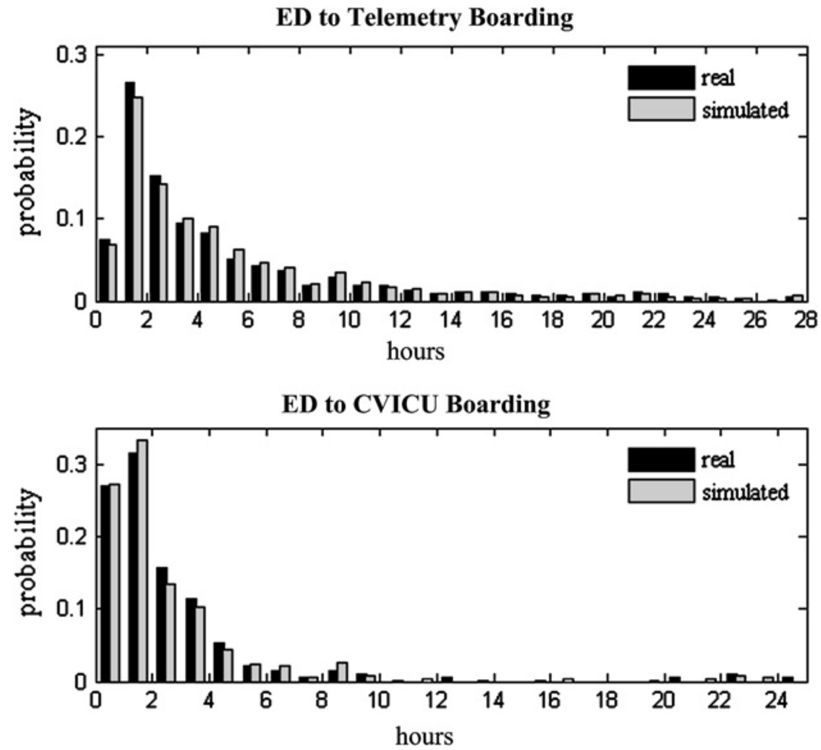

Figure 3 Comparison between real and simulated boarding times. CVICV, cardiovascular intensive care unit.

received 73% of these visits, with 20% arriving from the ED and 6% arriving from the OR. The CVICU received 27% of these visits, with 11% arriving from the ED and 33% arriving from the OR. Patients boarded for telemetry had a mean boarding time of 5.3 (median 3.1, interquartile range 1.5—6.9) h. Patients boarded for the CVICU had a mean boarding time of 2.7 (median 1.7, interquartile range 0.8—3.0) h. In comparison, the mean ED treatment time, excluding boarding time, was 4.1 (median 1.9, interquartile range 3.2—5.3) h. The average occupancy of the telemetry and CVICU units was 88% and 77%, respectively.

Effect of increasing surgical volume on ED boarding

There were 15 296 surgical procedures consisting of 1578 (10%) cardiac surgeries performed over the study period. The simulation was used to model the effects of increasing surgical volume on cardiac patient boarding time in the ED. The number of simulated weekly surgical procedures was increased by 10% increments, keeping the proportion of cardiac surgeries (10%) constant. The increase in surgical volume was distributed by day of week and hour of day in proportion to current scheduling. The effects of increasing surgical volume on boarding time to the telemetry unit and CVICU is shown in figure 4. Increasing surgical volume by 10% resulted in a 37 min (12%) increase in average boarding time to telemetry and a 33 min (20%) increase in average boarding time to the CVICU.

Informing cardiology inpatient expansion plans

The simulation was used to evaluate the effects of increased physical capacity (beds). Assuming that all other inputs, patient flow patterns and current system

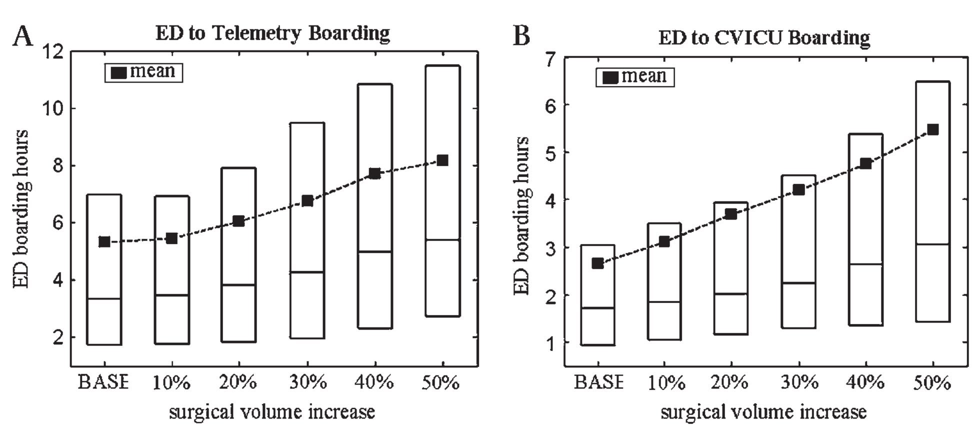

Figure 4 The effect on surgical volume increases on ED boarding time. (A) Boarding time to the telemetry unit. (B) Boarding time to the cardiovascular intensive care unit (CVICV).

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state outputs remained constant, increasing telemetry unit and CVICU capacity by one additional bed each produced a 9 min (3%) reduction in average boarding time to telemetry and a 7 min (4%) reduction in average boarding time to the CVICU. In comparison, one telemetry and CVICU bed should be added to accommodate each 16% (270 additional cardiac surgeries) and 11% (184) increase in surgical volume, respectively.

Reducing LOS

Reducing LOS for telemetry and CVICU patients will increase available staffed bed-hours that can be used to improve ED patient access or accommodate more surgical volume. The LOS distribution is easily altered within the simulation. However, the LOS of patients destined to the OR, CATH LAB or other hospital units may be dependent on the operations of their future location. Cardiology has the most control over LOS for (1) telemetry patients discharged home (73% of telemetry exits) and (2) CVICU patients transferred to telemetry or discharged home (69% of CVICU exits). Improving the efficiency of transfer and discharge processes, introducing provider incentives to discharge patients home earlier in the day and creating a discharge waiting area are methods that could decrease inpatient LOS. Fast-track protocols, postoperative critical pathways and staffing optimisation have also been suggested to reduce inpatient LOS.[19–23]

Reducing LOS of controllable telemetry and CVICU inpatients by 1 h resulted in a 7 min (2%) decrease in average boarding time to telemetry and an 8 min (5%) decrease in average boarding time to the CVICU. Instead of reducing boarding time, LOS reduction can free capacity to receive an increase in surgical patients. Figure 5 demonstrates how much LOS must be decreased to accommodate increases in surgical volume while maintaining current occupancy levels and ED boarding time distributions for cardiology patients. Reducing LOS for controllable telemetry and CVICU inpatients by 1 h gives cardiology the ability to receive 296 (19%) more surgical patients annually.

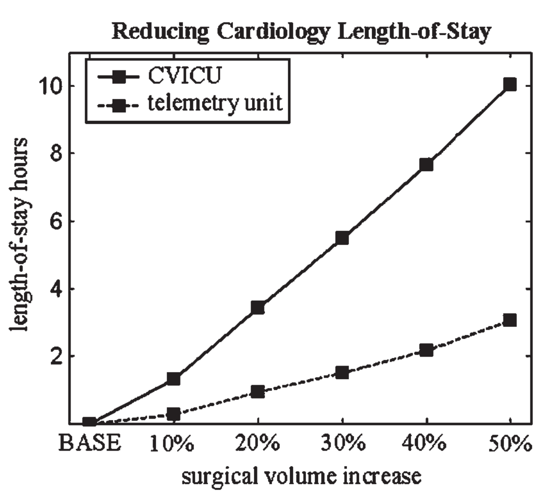

Figure 5 Reducing cardiology inpatient length of stay to accommodate an increase in surgical patients.

LIMITATIONS

A context of limitations should be considered when interpreting results of the simulation model. An important limitation concerns the development and application of assumptions made in representing (ie, modelling) the real-world system mathematically. For example, when introducing a change in the simulation, such as increasing cardiology capacity by one telemetry bed, an assumption to hold all other inputs (ie, arrivals and transfer patterns) constant was made. In the real-world system, increases in capacity could potentially result in an increase in arrivals, especially if demand for services exceeds supply. However, in the simulation, we control for all inputs (ie, hold them constant) so that we may be able to determine the sole effects of capacity changes on outputs. Although this method is helpful in determining direct cause and effects of a system change, it is not necessarily reflective of the real-world system. A similar assumption was made in holding transfer patterns constant. Assumptions must be made when developing a simulation model; however, it is important to understand how these assumptions limit interpretation of results. This should be examined thoroughly when changes to a simulated system are introduced with no empirical evidence of how true system dynamics will change.

CONCLUSIONS

A discrete-event simulation tool provided useful information to assist hospital administrators in planning for anticipated increases in surgical volume. The simulation results focused on the relationship between surgical volume and ED patient access to inpatient cardiac services. This relationship was determined by using hazard regression models that reflect the nature of competition for resources within a hospital macrosystem. The models quantify how increasing demand elevates competition and creates delays in access for ED patients. Embedding the "competition" regression models into a stochastic discrete-event simulation is a novel approach to examine the effects of future demand and prospective interventions.

The simulation results demonstrate how interventions (ie, increasing capacity or reducing LOS) have greater effects on the higher-priority surgical patients. Reducing LOS for 1 h produced trivial (7–8 min) decreases in average boarding time but an almost 20% increase in cardiac surgery throughput. Similar results are seen with increased cardiology bed capacity. US hospitals have the financial incentive to translate gains in efficiency and throughput towards elective surgical patients as opposed to ED patients. As long as financial incentives remain in place, economic pressures continue and no controls are implemented, the trade-offs between improving access (ie, delays) for electively scheduled surgical patients over ED patients will progress.

US hospitals must deal with conflicting priorities. While desiring to provide high-quality care, they must allocate bed capacity to assure their financial viability. Until these conflicts are addressed, it will be difficult for them to adhere to the Institute of Medicine's mandate to eliminate ED boarding and reduce ED crowding. System engineering tools, including simulation, allows hospitals to better navigate and plan in this discordant environment.[24] Hospitals should strive to use these tools to understand how scarce resources are being distributed, how competition for these resources affects healthcare access (ie, delays in care) and how proposed interventions may affect the system.[13 24]

Competing interests None.

Patient consent Obtained.

Ethics approval This study was conducted with the approval of the Vanderbilt University Institutional Review Board.

Provenance and peer review Not commissioned; externally peer reviewed.

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