



# An Electronic Dashboard to Monitor Patient Flow at the Johns Hopkins Hospital: Communication of Key Performance Indicators Using the Donabedian Model

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## Abstract

Efforts to monitoring and managing hospital capacity depend on the ability to extract relevant time-stamped data from electronic medical records and other information technologies. However, the various characterizations of patient flow, cohort decisions, sub-processes, and the diverse stakeholders requiring data visibility create further overlying complexity. We use the Donabedian model to prioritize patient flow metrics and build an electronic dashboard for enabling communication. Ten metrics were identified as key indicators including outcome (length of stay, 30-day readmission, operating room exit delays, capacity-related diversions), process (timely inpatient unit discharge, emergency department disposition), and structural metrics (occupancy, discharge volume, boarding, bed assignment duration). Dashboard users provided real-life examples of how the tool is assisting capacity improvement efforts, and user traffic data revealed an uptrend in dashboard utilization from May to October 2017 (26 to 148 views per month, respectively). Our main contributions are twofold. The former being the results and methods for selecting key performance indicators for a unit, department, and across the entire hospital (i.e., separating signal from noise). The latter being an electronic dashboard deployed and used at The Johns Hopkins Hospital to visualize these ten metrics and communicate systematically to hospital stakeholders. Integration of diverse information technology may create further opportunities for improved hospital capacity.

**Keywords** Systems engineering · Dashboard · Patient flow · Hospital capacity · Hospital overcrowding

## Introduction

Hospitals have increased efforts to monitor and manage patient flow as it is tightly linked to quality of care, patient

access, and hospital financial performance [1–3]. Time-stamped data from the electronic medical records (EMR) and other technologies are the main source of patient flow measurement [4], but the many characterizations of patient flow, cohort decisions, and sub-processes create challenges to separating actionable signal from noise. Diverse hospital stakeholders require data visibility through an array of lenses, creating further overlaying complexity.

The use of visual information reduces information overload and increases the understanding of data and the ability to remember information [5]. Dashboards leverage on visual information to support decision-making in multiple clinical contexts, and they have been found helpful to increase adherence to clinical guidelines and thus improved outcomes [6–15]. However, there is a scarcity of literature describing dashboards to monitor patient flow in hospitals and health systems [16]. In this paper, we describe the design and deployment of an electronic hospital capacity dashboard (e-Dashboard) at the Judy Reitz Capacity

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Command Center at The Johns Hopkins Hospital in Baltimore, Maryland (JHH-CCC). The process includes identifying users and their priorities, distinguishing key performance indicators, and describing the technical approach to build and deploy.

## Methods and intervention

### Setting and context

The Johns Hopkins Hospital (JHH) is a tertiary care center located in Baltimore, Maryland. Hospitals, as presented in Fig. 1, can be seen as a flow system (black pathways) with significant points of delay (grey bubbles). In the U.S., and depicted by the bolded pathway in Fig. 1, over half of total admissions originate in the ED (other major sources displayed in parallel pathways) [17, 18]. Deficiencies in ED inflow (ED visits), ED outflow (ED visits that are admitted to the hospital), hospital inflow (hospital admissions), and hospital outflow (hospital discharges) are complex interconnected root causes of hospital capacity inefficiencies. Since July 2014, JHH partnered with GE to prioritize strategies that would mitigate congestion and patient safety risks as well as accelerate patient throughput while preserving clinical excellence. The work was guided by functional unit directors, hospital executives, and additional stakeholders with clinical and systems engineering expertise (e.g., 19–29). After analysis of admission-discharge-transfer, emergency department, and outside hospital transfers data in combination with over 1000 h of interview and observations, a few key themes emerged as improvement opportunities at JHH. Among them, increase visibility and awareness of hospital operations dynamics at the JHH-CCC. Further description of this analysis is provided in [30]. In September 2015, an internal workgroup consisting of hospital administrators, data engineers and data scientists was formed to organize and prioritize patient flow metrics in the JHH-CCC, and to build the e-Dashboard to facilitate monitoring and communication to diverse stakeholders.

### User needs and key process indicators

From September to December 2015, the workgroup conducted multiple semi-structured interviews with the hospital leadership and the service and unit managers (e-Dashboard users) to understand the barriers to monitoring operations over time and driving change. Three major barriers were identified:

1. Limited number of authorized database administrators can access the JHH data warehouse;
2. Advanced programming and analytical skills—known to be a significant barrier for clinicians and administrators—

are required to extract valuable information from hospital information technologies;

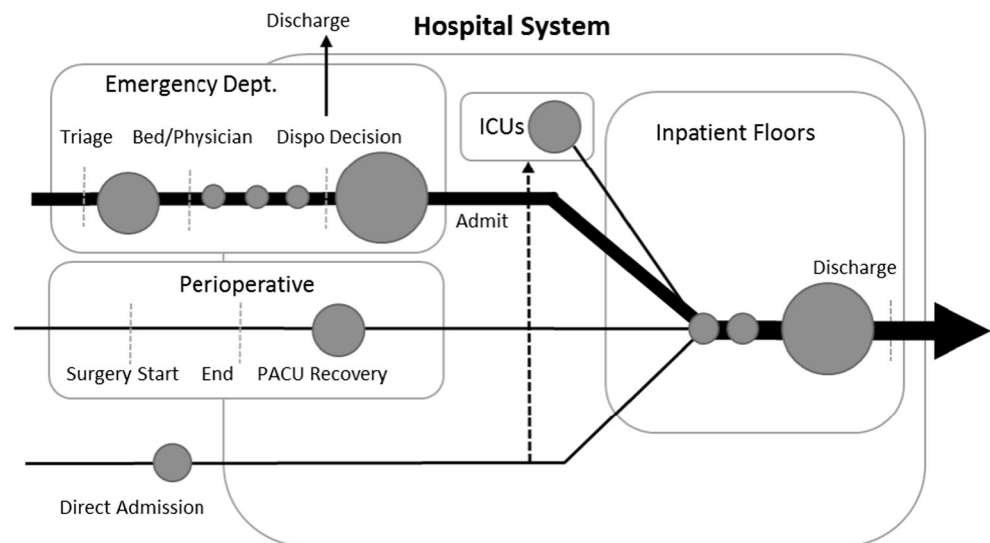
3. Current reports generated across clinical departments are inconsistent and have limited functionality with desired comparisons.

As shown in Table 1, we organized the identified key performance indicators (KPI) into three categories based on the Donabedian model [31]. To facilitate future comparisons of our hospital's performance to other medical centers within our health system, we decided to use Donabedian as it continues to be the preferred framework for the Agency for Healthcare Research and Quality and the patient safety and health services research communities [32]. We found that the hospital leadership was primarily concerned with 2-year trends of resource utilization and demand for each service (medicine, surgery, neurosciences, oncology, obstetrics and gynecology, pediatrics, psychiatry, and emergency department). On the other hand, service and unit managers were concerned with specific contingencies in the most recent periods (e.g., the average boarding duration from the ED to the inpatient wards in a given week). To fulfill the needs of the two user groups, we designed the e-Dashboard to show metrics by service, and then the users can drill down into specific units and time spans. From January to September 2016, our work team built the e-Dashboard. Important to note is that in July 2016 our institution faced full implementation of a new EMR system, which resulted in delays in our efforts due to the new sources of data.

### User needs and technical features

A prominent theme from the interviews was the desire to interact easily with data for further assessments. Grounded in human-computer interaction and visualization principles, the e-Dashboard provides a general overview of hospital operations and allows the users to zoom into specific time periods and select hospital units of interest through mouse clicking on tables and charts [33, 34]. The e-Dashboard also includes the use of color coding in the format of 'traffic light' approach [7, 9–12, 35], and it resides in a secure web environment with user authentication. Data tables are created in the back-end to reduce computation time in the front-end by bypassing computationally expensive table joins and loops. The e-Dashboard front-end was designed to be a web-based graphic user interface that communicates with a web server hosting the operational indicators. Due to the sensitive nature of the information presented on the e-Dashboard, the workgroup concluded that the JHH Intranet was the best alternative due to its easy to use, secure, and scalable characteristics. The JHH Intranet allows employees secure access to the e-Dashboard with "two clicks of their mouse".

**Fig. 1** The hospital as a patient flow system. Significant delays depicted as grey bubbles; major flux of patients displayed in black bolded pathways. Abbreviations: ICU, intensive care unit; PACU: Post-operative care unit



## Results

### Data visualization and analytics in e-Dashboard

Figure 2 presents the data analytics integrated into the e-Dashboard. The *Summary* view is a one-page overview of historical hospital operations. The Summary tab allows the user reorganize the data by sorting and applying filters to it. The user can also sort the data by arranging it alphabetically or numerically, apply a filter to narrow down the data and hide

some of it from view. The *Composition* views allow the user to understand the constituents and dynamics of hospital operations. It provides a picture of each KPI over time and tells the users the degree and type of variation at baseline to facilitate comparisons as improvement interventions are deployed. It includes tables and control charts with weekly KPIs of the most recent 12 months of operations. Tables and control charts allow ordering and applying filters to it, as well as the calculation of moving averages, lower and upper limits, and pre-specified performance targets. Such functionalities become

**Table 1** User needs and key process indicators (KPI) of the electronic hospital capacity dashboard (e-Dashboard). Users: U, unit leadership; S, service leadership; I, institutional leadership

	Emergency Department	Inpatient Floor	Perioperative Area <sup>b</sup>
<b>Outcome<sup>a</sup></b>			
30-Day Readmission Rate <sup>c,e</sup>			I
Length-of-Stay <sup>d,e</sup>	S	U	I U
Operating Room Exit Delay Volume and Duration			U S I
Capacity-Related Diversions Volume and Duration <sup>d</sup>		U	I U
<b>Process<sup>a</sup></b>			
Timely Discharge Order Rate		U S	U
Timely Discharge Rate		U S	U
ED Disposition Duration <sup>d</sup>	U	I	
<b>Structure<sup>a</sup></b>			
Hourly Bed Occupancy Rate <sup>d</sup>		U S	I U S
Hospital Discharge Volume <sup>c</sup>		U S	I U S
ED Boarding Duration <sup>d</sup>	U S	I U	I
ED Visits Volume <sup>c</sup>	U S	I	
Inpatient Bed Assignment Duration	U	I	

<sup>a</sup> Based on the Donabedian model of patient safety management: structure, factors that affect the context in which healthcare is delivered; process, all actions that make up healthcare; outcome, all the effects of healthcare on patients

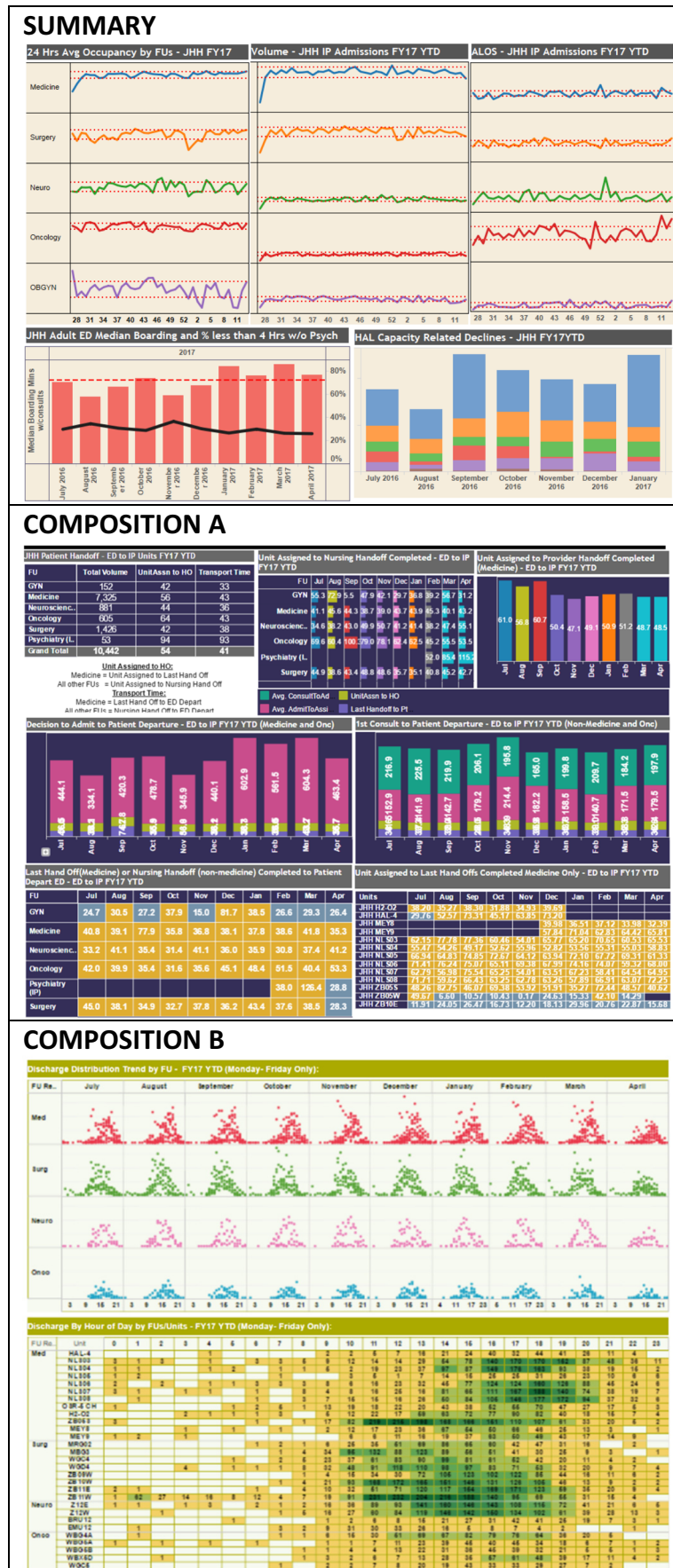
<sup>b</sup> Includes Labor and Delivery. Metric requested by the

<sup>c</sup> Requested by the National Committee for Quality Assurance

<sup>d</sup> Requested by the Joint Commission on the Accreditation of Health Care Organizations

<sup>e</sup> Requested by the Health Services Cost Review Commission

**Fig. 2** The graphical user interface of the electronic hospital operations dashboard (e-Dashboard)





important when identifying *special* versus *common* sources of variation. If *special* causes of variation are present, the hospital capacity optimization workgroup diagnosis its' root source and works to rectify. If common causes are present, more fundamental process change to reduce variability is required.

Limitations related to data availability and visualization are discussed next with the hope of inform development of future applications elsewhere. First, even with robust EHR implementation, we found it was challenging to pull timestamps related to the consultation process to monitor communication delays between the ED and inpatient services. As of June 2018, we were actively working with our EHR provider to build an EHR-embedded tool for performing consults that would track critical timestamps for hospital operations monitoring. Second, the creation of multiple dashboards challenges the user task of pinpointing the right piece of information. Steps ahead include the creation of an intranet portal where the dashboards will reside that will include keyword search functionality. Third and final, our data engineers are working on a whole health system real-time dashboard to facilitate performance comparisons among hospitals. This new project will require an enhanced Donabedian model that would control for patient and environmental factors that influence the measurement of quality of care. Our data scientists are using principles of control theory to monitor and compare hospitals' patient flows, and embed the resulting model into the e-Dashboard. Due to the daunting task of predicting the behavior of a complex adaptive system, such as the one exhibited by our health system, the value of this future step lies on the ability to provide insights regarding the dynamic and structural characteristics of our health system rather than predicting what will occur with patient flows.

### The usage of e-Dashboard

Figure 2—Composition A was used in weekly meetings of the leadership of the JHH-CCC to gauge the impact of initiatives on sub-cycle times. For instance, a new initiative aimed to “pre-assign” ED patients awaiting inpatient bed assignments so that provider-to-provider report could be given before the bed was ready. It was hypothesized that this would lower the sub-cycle time required for provider report. On reviewing the provider handoff data, however, the team found no decrease in providers' handoff duration. Further investigation discovered that only 10–20% of beds were being pre-assigned, thereby limiting the effect of the initiative on this sub-cycle time. This dashboard was also used in monitoring the impact of a pilot of electronic nursing handoff, which was piloted on specific units. The team saw the sub-cycle time required for nursing handoff drop with the new, asynchronous system.

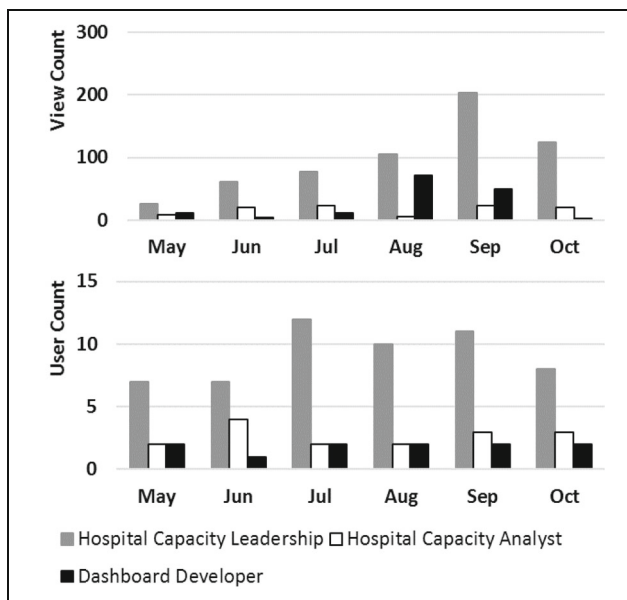
Mismatch between timing of discharges and requests for hospitalization causes ED operations to slow down during midday until ED boarders can be admitted to the hospital later

in the evening. Figure 2—Composition B supported an “aligned discharge” effort, in which pre-noon discharges were tracked by unit. The lower portion of Composition B, the heat map, was used to see “at a glance” when most discharges were occurring and how this varied by units. The top portion of Composition B visually displayed movement in discharge time over the months and was one dashboard used to track the progress of the aligned discharge initiative. These dashboards were primarily viewed at JHH-CCC leadership meetings when updating on this initiative.

We used a participatory design approach for the development of e-Dashboard in which stakeholders are directly involved in the research and development process. Direct involvement ensured they were represented and invested in the process, which infuses the definition, approach, execution, and outcome of a research effort with healthcare delivery perspective and priority. The e-Dashboard is distributed to the stakeholders using three mechanisms: viewing in meetings when projected, receiving in email form, and signing on to our institutional website (Tableau Software). We measured the number of views and unique visitors from May to October 2017. This measurement, however, represents a conservative estimate of usage, as some of the distribution mechanisms are impractical to track. For example, portions of Fig. 2—Composition A are periodically highlighted in an update email to all ED staff (400+ recipients), and graphs from this report are pasted into a short communication. As presented in Fig. 3, we found an uptrend on the number of views by administrators (from 26 to 148 views per month) while analysts and developers show a sideways trend (16 and 25 views per month, respectively). Although less abrupt, we also found an increase in the number of unique administrator users after June 2017 (from 7 to 11 per month). The number of analysts and developers remain constant during the study timeframe except August 2017, in which new tabs for the e-Dashboard were in development to support new hospital flow management initiatives.

### Discussion

The e-Dashboard provides hospital operations workgroups with a powerful, yet user-friendly venue, to benchmark operational performance and assess the impact of ongoing process improvement interventions at the hospital, service, and unit level. The e-Dashboard is not intended to be real-time but rather to promote retrospective evaluation by displaying longitudinal information of hospital operational performance. Before deployment, retrospective data of capacity performance were distributed in seven unique information systems that did not interface with each other. The e-Dashboard reduces the burden of collecting and analyzing data from multiple sources and thereby is likely to encourage acting on data for optimizing hospital capacity.



**Fig. 3** Usage of e-Dashboard from May to October 2017 by user type

Our results show how electronic dashboards support evidence-based decision-making to overcome hospital capacity inefficiencies. Two areas of current concern at our medical institution include streamlining patient handoff from the ED to the hospital floor and reducing hospital bed downtime. These two sub-processes, if performed poorly, not only may have a detrimental effect on patient outcomes but also in hospital performance by adding artificial wait times to an already prolonged length-of-stay [36]. As of May 2018, the e-Dashboard is still in place, but the addition of new data and visualizations became a necessity due to new efforts to improve patient flow. These interventions include new staffing models for the Department of Medicine, a new consultation process between the ED and the Department of Orthopedic Surgery, a novel technology to promote timely inpatient discharge [25], and lean initiatives to reduce bed downtime. In this last initiative, a multi-disciplinary team representing the ED, inpatient nursing, bed management, hospitalists, and the JHH-CCC designed interventions to reduce bed downtime by 33%. The bed downtime dashboard was used at weekly meetings to gauge performance. The broader distribution of bed downtime data was an intervention in itself; after refinement, the dashboard was sent via automated e-mail weekly to key stakeholders including the admitting hospitalists and bed managers.

Medical institutions across the U.S. are devoted to enhancing value through increased quality and reduced costs. National and regional accrediting bodies including the National Committee for Quality Assurance, the Joint Commission on the Accreditation of Health Care Organizations, and the Health Services Cost Review Commission request that hospitals prove the clinical quality and cost effectiveness of the care they provide [37–41]. In addition to some of the metrics requested by the previous accrediting bodies, an extra set of

operational and financial metrics were included in the e-Dashboard based on the strategic goals of our institution. These strategic goals include reducing ED wait by 30% and reducing delays in patients leaving the operating room by 20%. Current evidence shows that delays in moving patients from the ED to critical care units is associated with increased mortality [42–44]. Similarly, operating room exit delays are linked with worse patient outcomes and avoidable expenses [45, 46]. Based on available evidence, we hypothesize that delays in discharging patients is a major contributor to ED boarding and patient flow inefficiencies [47–49]. Concerns exist, however, that an emphasis on discharge timing may have detrimental effects on LOS and preventable readmissions [50]. Future work at our institution is in search of better understanding of the full effects of timely discharge interventions on patient outcomes and hospital operations. Nonetheless, we believe the e-Dashboard may assist on promoting accountability across units by asking them to prove, with quantifiable data, the clinical quality and the cost effectiveness of the care they provide.

This study has several important limitations. First, the visualizations included in the e-Dashboard are based on a reduced number of intended users rather than a systematic multi-site user needs assessment. Second, the academic medical center under study has a relatively mature quality information technology infrastructure. Therefore, our results might not be generalizable to other medical centers; however, the process by which the e-Dashboard was designed and deployed should be useful in analogous situations. Third, the Donabedian model imposes methodological restrictions at the time of comparing performance across hospitals as it fails to control for patient and environmental factors that influence the measurement of quality of care. Future work on expanding the use of the e-Dashboard across our health system requires the creation of a new model that addresses this issue. Fourth, the e-Dashboard might not translate into improved patient outcomes. Nonetheless, some of the metrics included in the e-Dashboard were accountability measures endorsed by national and regional accrediting bodies including The Joint Commission, supported by evidence, and associated with improved patient outcomes.

## Compliance with ethical standards

The authors whose names are listed above certify that they have no affiliations with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter or materials discussed in this manuscript.

## References

1. National Center for Health Statistics. Health, United States, 2015: With Special Feature on Racial and Ethnic Health Disparities. Hyattsville, MD; 2016.

2. Porter, M. E., What is value in health care? *N Engl J Med. Mass Medical Soc* 363(26):2477–2481, 2010.
3. Warden G, Griffin RB, Erickson SM, Mchugh M, Wheatley B, Dharshi AS, et al. Hospital-based emergency care: At the breaking point. 2006
4. Bates, D. W., Saria, S., Ohno-Machado, L., Shah, A., and Escobar, G., Big data in health care: Using analytics to identify and manage high-risk and high-cost patients. *Health Aff. Health Affairs* 33(7): 1123–1131, 2014.
5. Workman, M., An experimental assessment of semantic apprehension of graphical linguistics. *Comput Human Behav.* 24(6):2578–2596, 2008.
6. Linder JA, Schnipper JL, Tsurikova R, Yu DT, Volk LA, Melnikas AJ, et al. Electronic health record feedback to improve antibiotic prescribing for acute respiratory infections. *Am J Manag Care* [Internet]. 2010 Dec;16(12 Suppl HIT):e311–9. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/21322301>
7. Batley NJ, Osman HO, Kazzi AA, Musallam KM. Implementation of an emergency department computer system: Design features that users value. *J Emerg Med* [Internet]. 2011 Dec;41(6):693–700. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/20619572>
8. Pablate J. The effect of electronic feedback on anesthesia providers' timely preoperative antibiotic administration [Internet]. UNIVERSITY OF NORTH FLORIDA; 2009. Available from: <http://gradworks.umi.com/33/88/3388792.html>
9. Zaydfudim V, Dossett LA, Starmer JM, Arbogast PG, Feurer ID, Ray WA, et al. Implementation of a real-time compliance dashboard to help reduce SICU ventilator-associated pneumonia with the ventilator bundle. *Arch Surg* [Internet]. 2009 Jul;144(7):656–62. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/19620546>
10. Starmer J, Giuse D. A real-time ventilator management dashboard: Toward hardwiring compliance with evidence-based guidelines. *AMIA Annu Symp Proc* [Internet]. 2008;702–6. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/18998939>
11. McMenamin J, Nicholson R, Leech K. Patient Dashboard: The use of a colour-coded computerised clinical reminder in Whanganui regional general practices. *J Prim Health Care* [Internet]. 2011 Dec;3(4):307–10. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/22132384>
12. Morgan MB, Branstetter BF, Lionetti DM, Richardson JS, Chang PJ. The radiology digital dashboard: Effects on report turnaround time. *J Digit Imaging* [Internet]. 2008 Mar;21(1):50–8. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/17334871>
13. Badgeley MA, Shameer K, Glicksberg BS, Tomlinson MS, Levin MA, McCormick PJ, et al. EHDViz: Clinical dashboard development using open-source technologies. *BMJ Open* [Internet]. 2016;6(3):e010579. Available from: <http://bmjopen.bmj.com/lookup/doi/10.1136/bmjopen-2015-010579>
14. Agarwal, S., Joshi, A., Finin, T., Yesha, Y., and Ganous, T., A pervasive computing system for the operating room of the future. *Mob Networks Appl.* 12(2–3):215–228, 2007.
15. Benhamou P-Y. Improving diabetes management with electronic health records and patients' health records. *Diabetes Metab* [Internet]. Elsevier; 2011;37(4):S53–S56. Available from: [https://doi.org/10.1016/S1262-3636\(11\)70966-1](https://doi.org/10.1016/S1262-3636(11)70966-1)
16. WILBANKS BA, LANGFORD PA. A Review of Dashboards for Data Analytics in Nursing. *CIN Comput Informatics, Nurs* [Internet]. 2014 Nov;32(11):545–9. Available from: <http://content.wkhealth.com/linkback/openurl?sid=WKPTLP:landingpage&an=00024665-201411000-00006>
17. Kristy Gonzalez M, Bauhoff S, Blanchard JC, Abir NL, Smith A, Vesely J V, et al. The evolving role of emergency departments in the United States. *Rand Heal Q.* 2013;3(2).
18. Schuur, J., and Venkatesh, A., The growing role of emergency departments in hospital admissions. *N Engl J Med.* 367(5):391–393, 2012.
19. Strauss AT, Martinez DA, Garcia-Arce A, Taylor S, Mateja C, Fabri PJ, et al. A user needs assessment to inform health information exchange design and implementation. *BMC Med Inform Decis Mak* [Internet]. 2015 Dec;15(1):81. Available from: <http://www.biomedcentral.com/1472-6947/15/81>
20. Martinez, D. A., Mora, E., Gemmani, M., and Zayas-Castro, J. L., Uncovering hospitalists' information needs from outside healthcare facilities in the context of health information exchange using association rule learning. *Appl Clin Inform.* 6(4):684–697, 2015.
21. Martinez, D. A., Tsalatsanis, A., Yalcin, A., Zayas-Castro, J. L., and Djulbegovic, B., Activating clinical trials: A process improvement approach. *Trials. BioMed Central* 17(1):1, 2016.
22. France, D. J., Levin, S., Hemphill, R., Chen, K., Rickard, D., Makowski, R. et al., Emergency physicians' behaviors and workload in the presence of an electronic whiteboard. *Int J Med Inform.* Elsevier 74(10):827–837, 2005.
23. Hoot, N. R., LeBlanc, L. J., Jones, I., Levin, S. R., Zhou, C., Gadd, C. S. et al., Forecasting emergency department crowding: A prospective, real-time evaluation. *J Am Med Informatics Assoc.* Elsevier 16(3):338–345, 2009.
24. Toerper MF, Flanagan E, Siddiqui S, Appelbaum J, Kasper EK, Levin S. Cardiac catheterization laboratory inpatient forecast tool: A prospective evaluation. *J Am Med Informatics Assoc.* The Oxford University Press; 2015;ocv124.
25. Barnes S, Hamrock E, Toerper M, Siddiqui S, Levin S. Real-time prediction of inpatient length of stay for discharge prioritization. *J Am Med Informatics Assoc.* The Oxford University Press; 2015;ocv106.
26. Hamrock, E., Parks, J., Scheulen, J., and Bradbury, F. J., Discrete event simulation for healthcare organizations: A tool for decision making. *J Healthc Manag. Health Administration Press* 58(2):110, 2013.
27. Scheulen, J. J., Li, G., and Kelen, G. D., Impact of ambulance diversion policies in urban, suburban, and rural areas of Central Maryland. *Acad Emerg Med. Wiley Online Library* 8(1):36–40, 2001.
28. Kelen, G. D., Kraus, C. K., McCarthy, M. L., Bass, E., Hsu, E. B., Li, G. et al., Inpatient disposition classification for the creation of hospital surge capacity: A multiphase study. *Lancet. Elsevier* 368(9551):1984–1990, 2006.
29. Brooks D, Rupani H. Real-time demand capacity and patient throughput management dashboard. 14/436,494, 2013.
30. Kane E, Scheulen J, Martinez D, Levin S, Busch B, Jacobs MM, et al. Use of Systems Engineering to Design a Hospital Command Center. In *The Joint Commission Journal on Quality and Patient Safety*; 2018.
31. Donabedian A. The Quality of Care. *JAMA* [Internet]. 1988 Sep 23;260(12):1743. Available from: <http://jama.jamanetwork.com/article.aspx?doi=10.1001/jama.1988.03410120089033>
32. Agency for Healthcare Research and Quality. Types of Quality Measures [Internet]. Rockville, MD; 2011 [cited 2018 May 5]. Available from: <http://www.ahrq.gov/professionals/quality-patient-safety/talkingquality/create/types.html>
33. Shneiderman B. The eyes have it: A task by data type taxonomy for information visualizations. In: *Visual Languages, 1996 Proceedings, IEEE Symposium on.* 1996. p. 336–43.
34. Shneiderman, B., and Plaisant, C., Designing the user interface: Strategies for effective human-computer interaction. *ACM SIGBIO Newsl. ACM* 9(1):6, 1987.
35. Koopman RJ, Kochendorfer KM, Moore JL, Mehr DR, Wakefield DS, Yadamsuren B, et al. A diabetes dashboard and physician efficiency and accuracy in accessing data needed for high-quality diabetes care. *Ann Fam Med* [Internet]. 9(5):398–405. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/21911758>
36. Ong M-S, Coiera E. A systematic review of failures in handoff communication during intrahospital transfers. *Jt Comm J Qual*

- patient Saf [Internet]. 2011 Jun;37(6):274–84. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/21706987>
37. Denton TA, Matloff JM. Optimizing cardiothoracic surgery information for a managed care environment. *Ann Thorac Surg* [Internet]. 1995 Nov;60(5):1522–5. Available from: <http://linkinghub.elsevier.com/retrieve/pii/000349759594076D>
  38. Ellwood PM, Enthoven AC. “Responsible choices”: The Jackson Hole Group plan for health reform. *Health Aff (Millwood)* [Internet]. 1995;14(2):24–39. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/7657245>
  39. Solberg LI, Mosser G, McDonald S. The three faces of performance measurement: Improvement, accountability, and research. *Jt Comm J Qual Improv* [Internet]. 1997 Mar;23(3):135–47. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/9103968>
  40. The “patient flow standard” and the 4-hour recommendation. *Jt Comm Perspect* [Internet]. 2013 Jun;33(6):1, 3–4. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/23785957>
  41. Rajkumar R, Patel A, Murphy K, Colmers JM, Blum JD, Conway PH, et al. Maryland’s All-Payer Approach to Delivery-System Reform. *N Engl J Med* [Internet]. 2014 Feb 6;370(6):493–5. Available from: <http://www.nejm.org/doi/abs/10.1056/NEJMp1314868>
  42. Chalfin DB, Trzeciak S, Likourezos A, Baumann BM, Dellinger RP, DELAY-ED study group. Impact of delayed transfer of critically ill patients from the emergency department to the intensive care unit. *Crit Care Med* [Internet]. 2007 Jun;35(6):1477–83. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/17440421>
  43. Hager DN, Chandrashekar P, Bradsher RW, Abdel-Halim AM, Chatterjee S, Sawyer M, et al. Intermediate care to intensive care triage: A quality improvement project to reduce mortality. *J Crit Care* [Internet]. 2017 Dec;42:282–8. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/28810207>
  44. Harris S, Singer M, Rowan K, Sanderson C. Delay to admission to critical care and mortality among deteriorating ward patients in UK hospitals: A multicentre, prospective, observational cohort study. *Lancet (London, England)* [Internet]. 2015 Feb 26;385 Suppl:S40. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/26312862>
  45. McGowan JE, Truitt JD, Cipriano P, Howell RE, VanBree M, Garson A, et al. Operating room efficiency and hospital capacity: Factors affecting operating room use during maximum hospital census. *J Am Coll Surg* [Internet]. 2007 May;204(5):865–71-2. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/17481500>
  46. Dexter F, Epstein RH, Marcon E, de Matta R. Strategies to reduce delays in admission into a postanesthesia care unit from operating rooms. *J perianesthesia Nurs Off J Am Soc PeriAnesthesia Nurses* [Internet]. 2005 Apr;20(2):92–102. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/15806526>
  47. Powell ES, Khare RK, Venkatesh AK, Van Roo BD, Adams JG, Reinhardt G. The relationship between inpatient discharge timing and emergency department boarding. *J Emerg Med* [Internet]. 2012 Feb;42(2):186–96. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/20888163>
  48. Wertheimer B, Jacobs REA, Bailey M, Holstein S, Chatfield S, Ohta B, et al. Discharge before noon: An achievable hospital goal. *J Hosp Med* [Internet]. 2014 Apr;9(4):210–4. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/24446232>
  49. Wertheimer B, Jacobs REA, Iturrate E, Bailey M, Hochman K. Discharge before noon: Effect on throughput and sustainability. *J Hosp Med* [Internet]. 2015 Oct;10(10):664–9. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/26126432>
  50. Rajkomar A, Valencia V, Noveler M, Mourad M, Auerbach A. The association between discharge before noon and length of stay in medical and surgical patients. *J Hosp Med* [Internet]. 2016 Dec;11(12):859–61. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/26717556>