The Joint Commission Journal on Quality and Patient Safety 2019; 000:1–10

Use of Systems Engineering to Design a Hospital Command Center

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Background: In hospitals and health systems across the country, patient flow bottlenecks delay care delivery—emergency department boarding and operating room exit holds are familiar examples. In other industries, such as oil, gas, and air traffic control, command centers proactively manage flow through complex systems.

Methods: A systems engineering approach was used to analyze and maximize existing capacity in one health system, which led to the creation of the Judy Reitz Capacity Command Center. This article describes the key elements of this novel health system command center, which include strategic colocation of teams, automated visual displays of real-time data providing a global view, predictive analytics, standard work and rules-based protocols, and a clear chain of command and guiding tenets. Preliminary data are also shared.

Results: With proactive capacity management, subcycle times decreased and allowed the health system's flagship hospital to increase occupancy from 85% to 92% while decreasing patient delays.

Conclusion: The command center was built with three primary goals—reducing emergency department boarding, eliminating operating room holds, and facilitating transfers in from outside facilities—but the command center infrastructure has the potential to improve hospital operations in many other areas.

PROBLEM DEFINITION AND CONTEXT

In the inpatient setting, hospital gridlock often delays patient movement to the optimal location for care. Emergency department (ED) crowding and boarding, which stem from systemwide inefficiencies,[1–3] have been directly linked to higher inpatient morbidity, preventable harm, and overall mortality, as well as increased total inpatient length of stay and decreased patient satisfaction.[4–16] Operating room (OR) exit holds, in which patients are unable to move from the OR to the postanesthesia care unit (PACU) or the ICU due to capacity constraints, are associated with worse patient outcomes and avoidable expense.[17,18] Delays in moving patients to critical care units are associated with increased mortality.[19–21] At tertiary care centers, inefficiencies often limit the number of patients eligible for transfer in from surrounding community hospitals, thereby delaying or preventing access to care.

Many approaches have been tried to address boarding and crowding, such as monitoring of bed turnaround time, OR schedule smoothing, telemedicine consults, Lean and Plan–Do–Study–Act (PDSA) rapid cycle improvement, and many more.[2,5,22,23] Despite this, crowding continues to increase, leading The Joint Commission to require hospitals to measure and address ED boarding and the Centers for Medicare & Medicaid Services to include related metrics in public reporting.[22,24] New approaches to flow management are vital to effect and sustain change.[25,26]

At the Johns Hopkins Hospital (JHH), we used a systems engineering approach to analyze and maximize existing capacity, which led to the creation of the Judy Reitz Capacity Command Center. To our knowledge, this is the first hospital command center of this scale and breadth to be described in the literature. Previously, hospitals have had more limited transfer centers or access centers[27,28] used to facilitate the movement of patients from outside hospitals, as well as bed management centers with a more comprehensive view of total hospital bed allocation.[29,30] More recently, some institutions have described an expanded operations center approach to managing patient flow.[31–33] Our work builds on these and incorporates many of the approaches to boarding that have been described previously.

Our effort is unique in several key ways. The Capacity Command Center (CCC) centralizes previously isolated administrative processes and local performance initiatives. This global view is essential to prioritize projects, share best practices, and standardize work across the hospital. Further, the CCC is novel in the degree to which it incorporates real-time data, predictive analytics, and simulation modeling through its grounding in systems engineering. Finally, the CCC's permanence, as signaled by its physical infrastructure and organizational integration, provides a longitudinal and persistent platform for culture change.

To achieve the broader mission and vision of proactively managing patient flow throughout an institution, examples were taken from industries outside of health care. Industries

1553-7250/$-see front matter

https://doi.org/10.1016/j.jcjq.2018.11.006

Table 1. Command Center Teams

Team	Function	Workload
Hopkins Access Line (HAL)	Connects physicians by phone, including for transfer requests, and activates emergency teams	20,000 calls monthly, including 700 transfer requests
Admission Services	Processes registration and insurance notification for all patients	170 admissions per day, including hospitalizations and OR admissions
HopComm/Lifeline	Transports patients between facilities by air or ground and performs critical care transport in-hospital	3,000 transports monthly
Bed Management nursing coordinators	Assign patients with a pending bed request from the ED, the admitting office, the PACU, or an outside facility to an appropriate inpatient unit	100–130 patients matched to beds daily
Capacity Optimization leadership group	Drives strategic and operational initiatives Led by Chief Administrative Officer for Capacity Management Director of Patient/Family and Visitor Services, and Medical Director of Capacity Management	30–40 projects ongoing

OR, operating room; ED, emergency department; PACU, postanesthesia care unit.

such as oil and gas, air traffic control, NASA, the Olympics, and entire city governments have developed command centers to proactively manage operations.[34–38] Core elements of these command centers that we replicated include strategic colocation of teams, automated visual displays of real-time data providing a global view, predictive analytics, standard work and rules-based protocols, and a clear governance structure and guiding tenets.

Our capacity optimization journey began with three primary goals: (1) expediting admissions from the ED and reducing ED boarding, (2) streamlining perioperative flow and eliminating OR holds, and (3) facilitating critical transfers from outside facilities. The key elements of the CCC, described below, were developed with these goals and models from other industries in mind.

INITIAL APPROACH

The JHH is the flagship hospital for the six-hospital Johns Hopkins Health System and is a 1,131-bed tertiary care hospital located in Baltimore. In 2017 there were more than 65,000 ED visits and 48,000 admissions; 18% of admissions were transfers from outside facilities via the Hopkins Access Line (HAL). Average operational occupancy across all inpatient units is 90%, with a 95% average occupancy for the Department of Medicine.

The Judy Reitz Capacity Command Center is physically composed of 5,500 square feet of space with 38 workstations, three conference rooms, and eight offices surrounding 22 digital screens with 13 real-time analytic tiles feeding in data from seven different sources (Figure 1). The development of the CCC required physical, human, and capital resources. Physical space was allocated in a central location in the hospital. The majority of the staff came from four preexisting departments that were consolidated, and a few new positions were funded specifically for the CCC. Computer hardware and engineering was an upfront cost, and ongoing financial support has been built into the hospital budget.

Colocation of Key Teams

When a patient is admitted to the JHH, up to four teams are involved: (1) the HAL, or transfer line that connects physicians, (2) Admission Services, (3) Lifeline transport, and (4) Bed Management (Table 1). The process begins with a request for an admission bed, which may be for a scheduled/planned admission or for an admission via the ED or from an outside hospital via HAL. Next, a nursing bed management coordinator identifies an appropriate bed and assigns it to that patient. If no bed is available at the time of request, the patient is placed in a queue until a bed can be assigned. After a bed is assigned, Lifeline facilitates transport in for patients transferred from outside hospitals, and Admission Services processes registration. All patients are touched by a minimum of two of the four teams.

In designing the CCC, we intentionally colocated these teams. Literature from other industries, in particular software engineering, has demonstrated that teams separated by even 30 meters take 2.5 times as long to complete a project as a colocated team.[39] Colocation has been studied and found to be key in a range of industries, including government programming and health services.[40–43] The reasons for this are thought to be both formal and informal mechanisms used to coordinate work. In one striking example from the transportation industry, authors highlight how colocation yields efficiencies: "operators of the London Underground developed ways of working together without specifically coordinating their efforts, relying on speaking out loud and monitoring."[39(p. 320)] When the person responsible for scheduling the trains told a train driver to

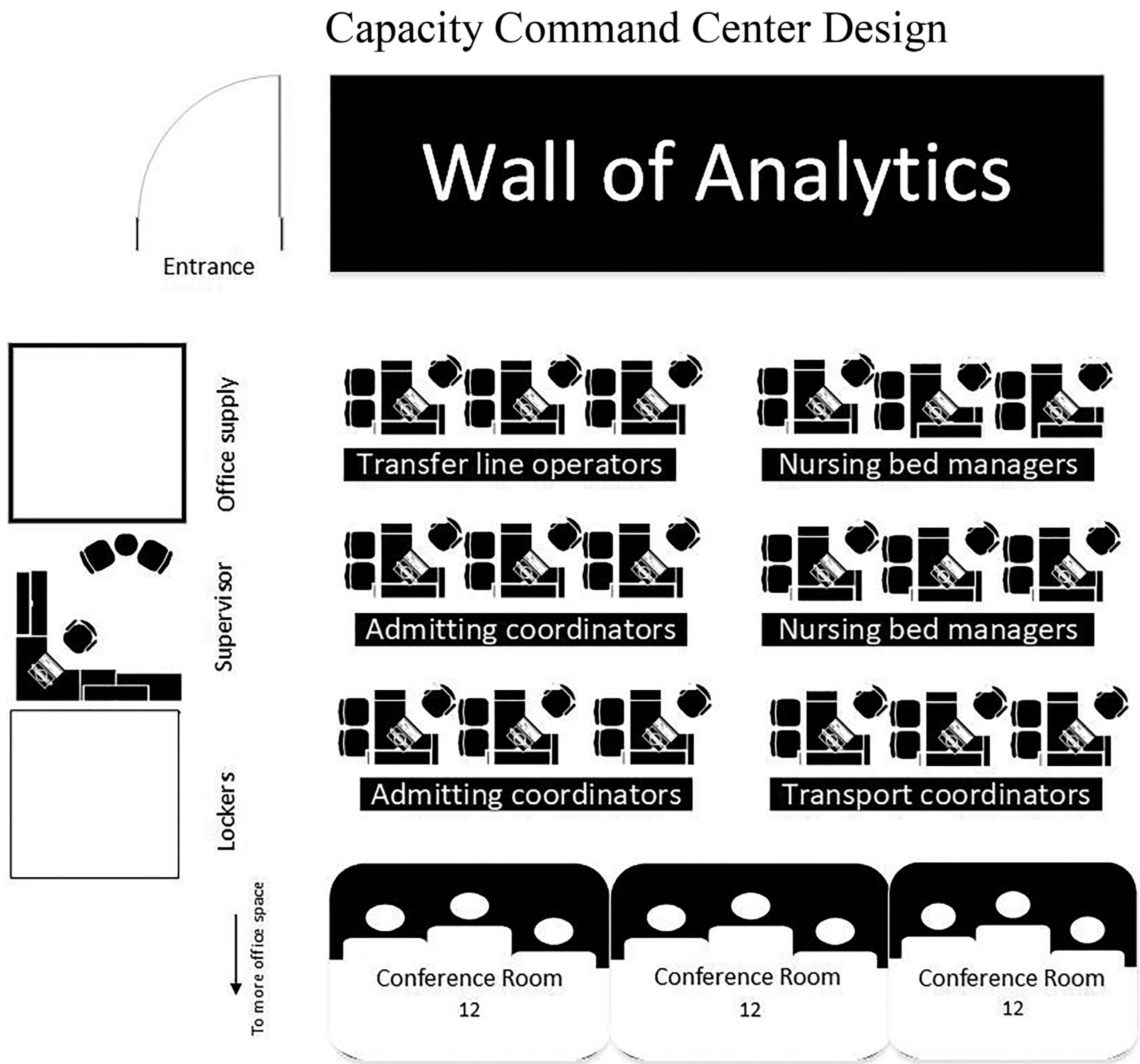


Figure 1: The current configuration of the Capacity Command Center includes nursing bed management coordinators, transfer line operators, admitting coordinators, transport coordinators, and drop-in workspace.

slow down, the person responsible for passenger announcements responded by announcing overhead that the next train would be delayed.[39] In our case, teams that would previously communicate by fax, page, or phone now communicate in person. For instance, the Lifeline operators coordinate with the HAL expeditors to dispatch critical care transport teams.

Real-Time Data

At the time of initiation of the project, data related to patient flow and hospital capacity were distributed in seven unique systems that, for the most part, did not interface with each other. The data could be accessed but with significant effort and time for each instance. At the heart of the CCC are the "tiles" that project integrated feeds from all relevant data sources and provide data in real time. These collective tiles form the Wall of Analytics®, which was developed in partnership with GE Healthcare (Figure 2). Teams of engineers, data analysts, administrators, physicians, and nurses designed the tiles sequentially. The tiles are not intended to be static or retrospective but rather to promote immediate and timely action by displaying real-time and predictive analytics.

Analytics can be described along a continuum: descriptive, diagnostic, predictive, and prescriptive.[44–47] To start, active collection and collation of real-time descriptive data enhanced our ability to make decisions in a timely manner. As the CCC matures, the tiles have been refined to incorporate more predictive and prescriptive capabilities. Predictive data forecast occupancy and wait times, while prescriptive tiles provide decision support for CCC staff, such as a recommended bed placement. The CCC tiles extract data

Sample Tiles on the Wall of Analytics

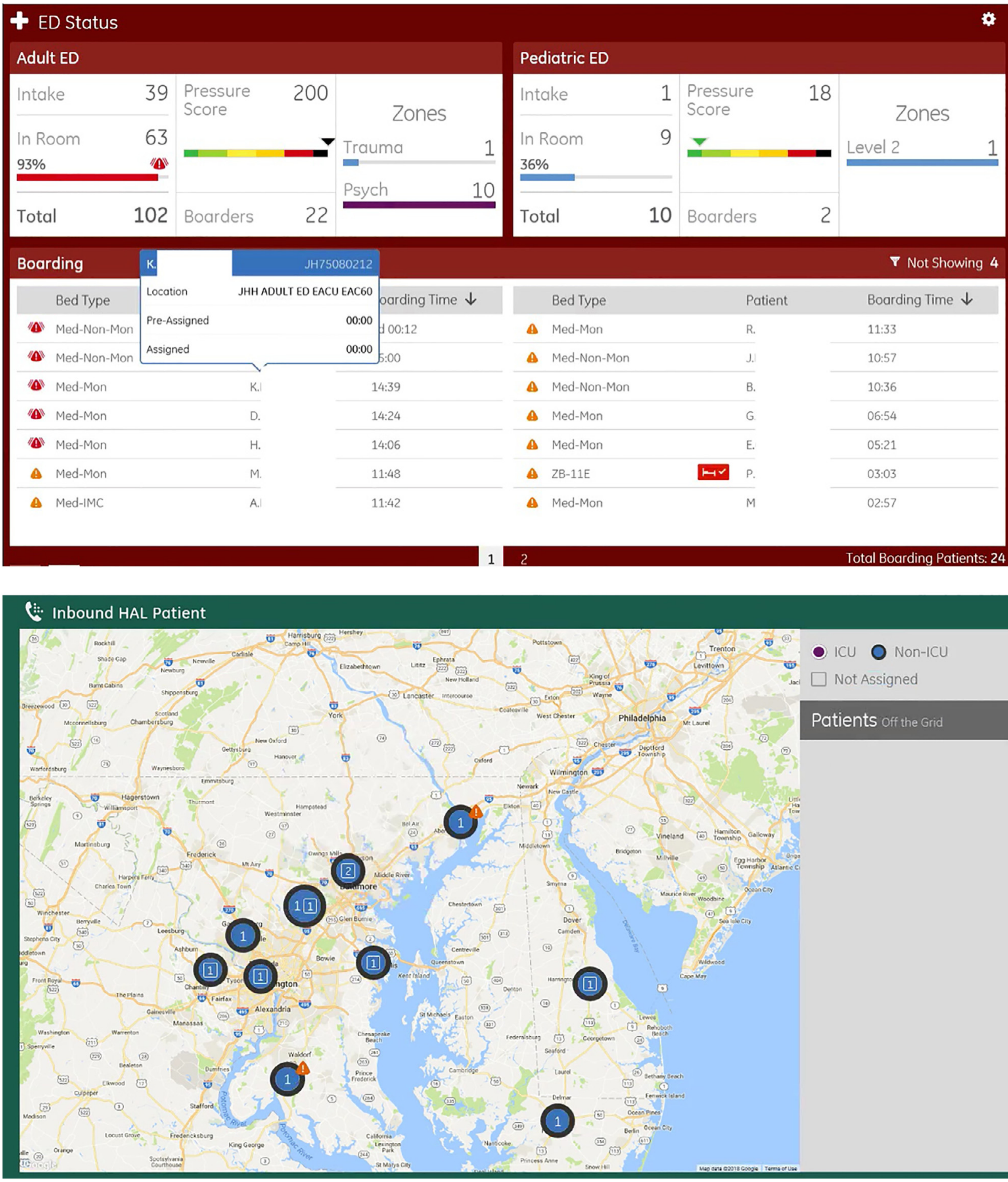
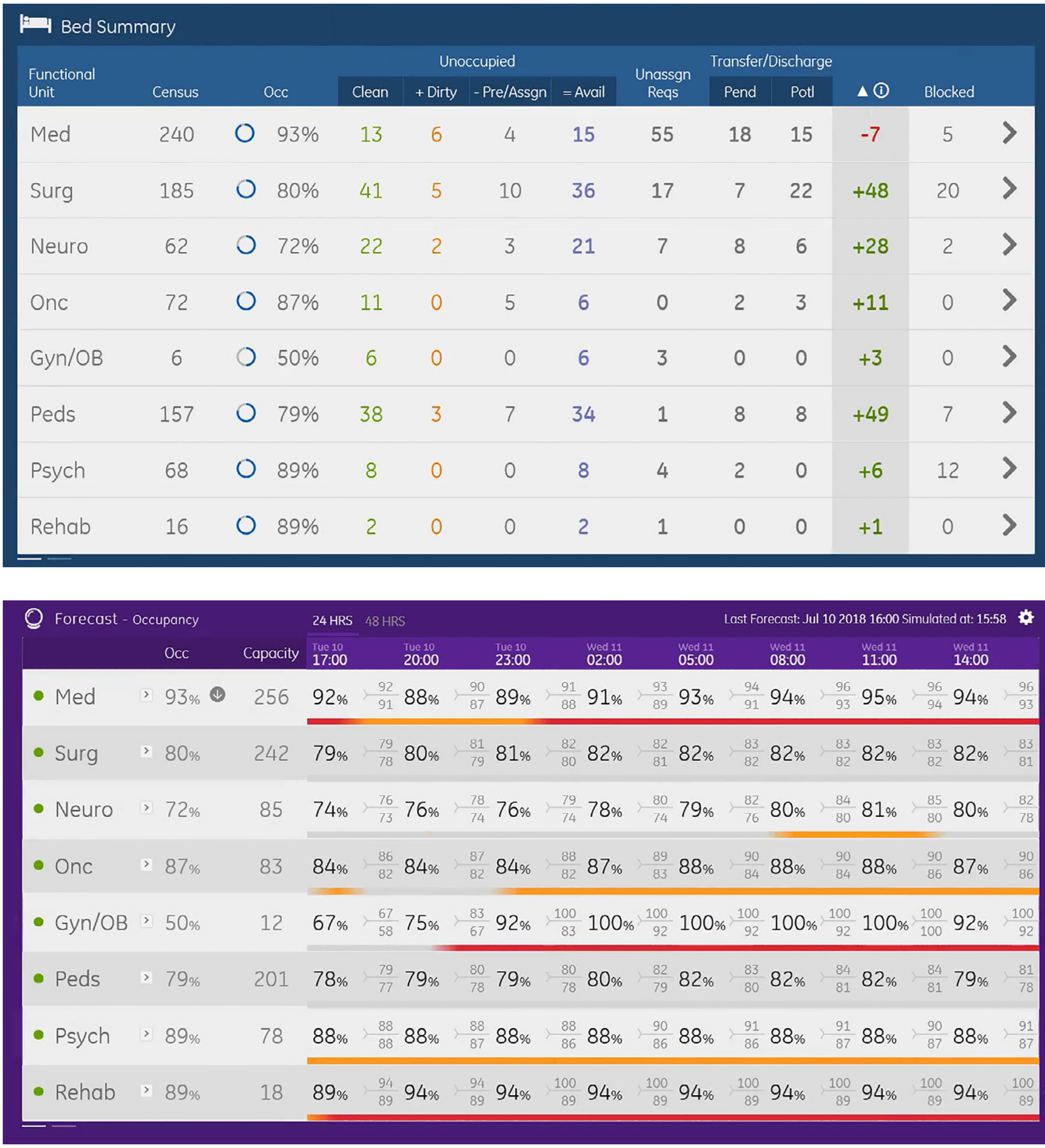


Figure 2: There are 14 total tiles on the Wall of Analytics. Tiles update in real time, and initial design required integration of data streams from seven different systems. Four examples of tiles are included here: the ED status tile, which displays adult and pediatric ED census and boarders along with boarding time; the inbound HAL patient tile, which gives a visual representation of patients awaiting bed assignment and transport (including visual cues for ICU and ED patients); the bed summary tile, which gives an accounting for bed availability by functional unit and drills down to the unit level when clicked; and the forecast occupancy tile, which uses predictive analytics to project census for the next 48 hours. ED, emergency department; HAL, Hopkins Access Line.



Bed Summary

Functional Unit	Census	Occ	Unoccupied Clean	+ Dirty	- Pre/Assgn	= Avail	Unassgn Reqs	Transfer/Discharge Pend	Potl	▲ ⓘ	Blocked
Med	240	93%	13	6	4	15	55	18	15	-7	5
Surg	185	80%	41	5	10	36	17	7	22	+48	20
Neuro	62	72%	22	2	3	21	7	8	6	+28	2
Onc	72	87%	11	0	5	6	0	2	3	+11	0
Gyn/OB	6	50%	6	0	0	6	3	0	0	+3	0
Peds	157	79%	38	3	7	34	1	8	8	+49	7
Psych	68	89%	8	0	0	8	4	2	0	+6	12
Rehab	16	89%	2	0	0	2	1	0	0	+1	0

Forecast - Occupancy 24 HRS 48 HRS Last Forecast: Jul 10 2018 16:00 Simulated at: 15:58

	Occ	Capacity	Tue 10 17:00		Tue 10 20:00		Tue 10 23:00		Wed 11 02:00		Wed 11 05:00		Wed 11 08:00		Wed 11 11:00		Wed 11 14:00	
Med	93%	256	92%	92/91	88%	90/87	89%	91/88	91%	93/89	93%	94/91	94%	96/93	95%	96/94	94%	96/93
Surg	80%	242	79%	79/78	80%	81/79	81%	82/80	82%	82/81	82%	83/82	82%	83/82	82%	83/82	82%	83/81
Neuro	72%	85	74%	76/73	76%	78/74	76%	79/74	78%	80/74	79%	82/76	80%	84/80	81%	85/80	80%	82/78
Onc	87%	83	84%	86/82	84%	87/82	84%	88/82	87%	89/83	88%	90/84	88%	90/84	88%	90/86	87%	90/86
Gyn/OB	50%	12	67%	67/58	75%	83/67	92%	100/83	100%	100/92	100%	100/92	100%	100/92	100%	100/100	92%	100/92
Peds	79%	201	78%	79/77	79%	80/78	79%	80/78	80%	82/79	82%	83/80	82%	84/81	82%	84/81	79%	81/78
Psych	89%	78	88%	88/88	88%	88/87	88%	88/86	88%	90/86	88%	91/86	88%	91/87	88%	90/87	88%	91/87
Rehab	89%	18	89%	94/89	94%	94/89	94%	100/89	94%	100/89	94%	100/89	94%	100/89	94%	100/89	94%	100/89

Figure 2: Continued

from disparate systems, process them, and display them in a way that is digestible and actionable for the end user.

In addition to real-time data feeds, dashboards summarizing historical trends on key metrics were developed as part of the capacity optimization effort. Though not displayed in the CCC, these have been integral to leadership meetings and are used to guide strategic and operational efforts.

Standard Operating Procedures

Standard operating procedures (SOPs) that emphasize high reliability and low variability were developed and detailed in a written manual. These describe who in the CCC responds to information on the tiles and what action should be taken. They are organized around the three primary goals of reducing ED boarding, streamlining perioperative flow and eliminating OR holds, and facilitating transfers from outside hospitals. For example, one of a series of SOPs that governs perioperative flow describes actions when a patient in the PACU is not cleared within 90 minutes: A red triangle that appears on the procedural tile triggers the PACU charge nurse to conference with the bedside nurse and contact the anesthesiologist, who clears the patient if appropriate. Target time frames are included in the SOP.

SIMULATION MODELING

Complex simulation models combining discrete event simulation (DES) and agent-based simulation (ABS) were built to help prioritize initiatives intended to address overarch-

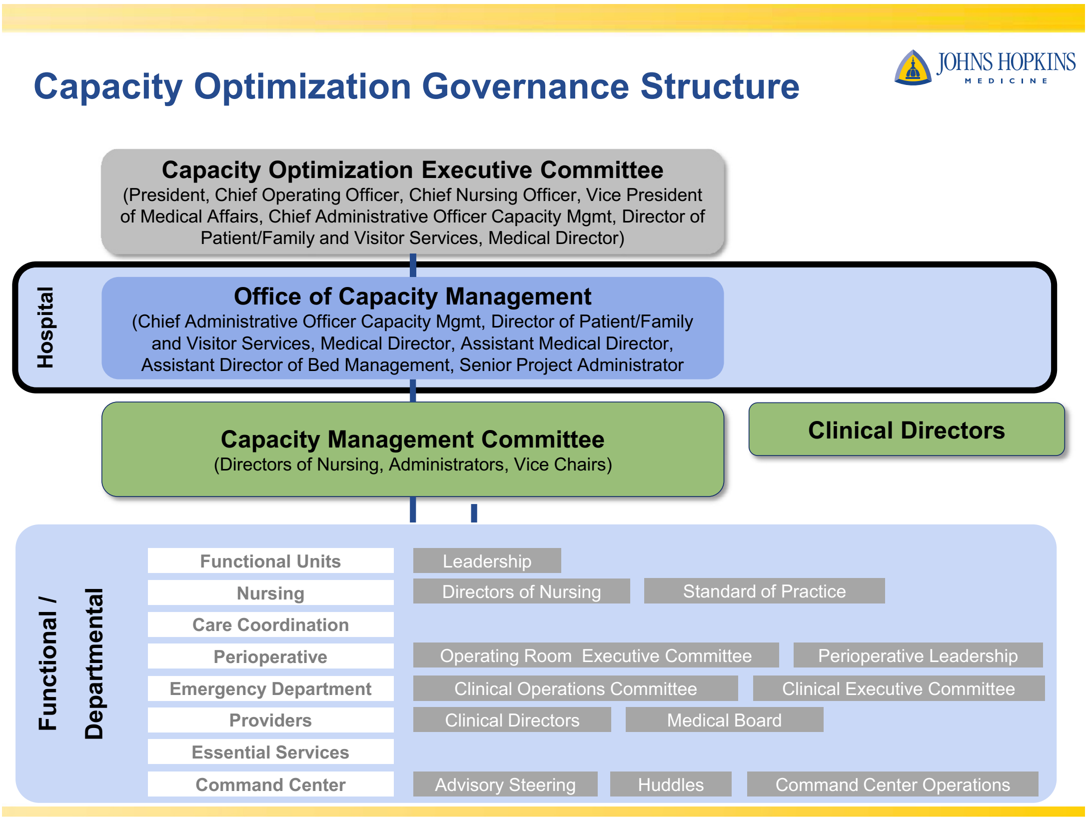


Figure 3: The governance structure for capacity optimization is shown in this organizational chart. The core leadership group for the Capacity Command Center meets weekly and drives strategic and operational initiatives.

ing capacity goals. DES is a computerized method of imitating the operation of a process over time. In health care, DES often focuses on the allocation of physical and human resources and its effect on patient flow. These DES models are comprised of entities (for example, patients, laboratory tests) that flow through the modeled system, resources that process entities, locations, and arrival and processing interval distributions.[48] Alternatively, ABS is a computational method of imitating the behavior of entities (for example, patients, physicians) and interactions between them. ABS in health care commonly focuses on how people make decisions within a process. ABS is particularly helpful when health care delivery process changes are a function of the entities' behavior, rather than an input of the model (that is, agents decide what process to follow next).[49]

In brainstorming potential solutions to our capacity challenges, teams considered a wide variety of options (fully staffed ICUs, additional monitored beds, timely hospital discharge, implementation of an extended stay unit, the creation of a pediatric observation unit, decreasing PACU length of stay, and many others). Simulation modeling was used to predict the impact of each. With this quantification of expected impact, the slate of initiatives could be more intelligently prioritized. For instance, one of the multiple scenarios tested in the simulations was the shifting of 13 underutilized Medicine beds from an older section of the hospital to a newer area. The work group hypothesized that moving these beds would have a significant impact on ED boarding due to shorter transport times and easier patient flow, but simulation modeling showed minimal effects on boarding times, so other initiatives were prioritized instead, including adjusting Medicine staffing to better match admission requests and reducing "bed downtime" between inpatient admissions.

Technical aspects of these simulation models have been described elsewhere.[50,51] Use of simulation modeling is key to our ongoing operations.

Governance

The governance structure for the CCC has been essential to our success. Planning for the CCC began in the summer of 2014 as an extension of a previously existing, multidisciplinary Patient Flow Workgroup. With consultative support from GE Healthcare, the JHH placed the project under the administrative leadership of the Chief Administrative Officer of Capacity Management and the Director of Patient and Visitor Services. A steering committee for the project was formed and includes the Johns Hopkins Health System CEO, Chief Information Officer (CIO), and chief operating officer (COO), the JHH President and Vice President for Medical Affairs, the JHH Director of Nursing, selected School of Medicine department directors, and the CCC project leaders.

Capacity Optimization Timeline

	Summer 2014 - 2015	2016 - 2017	2018 - Ongoing
Governance	Planning for Capacity Command Center (CCC) begins Steering committee and workgroups convened	Office of Capacity Management finalized and meeting weekly Year in Review	Increasing collaboration with other hospitals in system Updated CCC mission / vision
Physical and structural	CCC space designed and built Tiles on Wall of Analytics developed; real-time data feeds integrated	Key groups move into CCC Opening of CCC 11th and 12th tiles added	14th tile planning
Project-related milestones*	Bed management centralized CCC standard operating procedures established Initial peri-operative work	OR scheduling centralized High occupancy plan go-live Bed downtime projects launched	Medicine staffing restructured Peri-operative teams renew OR hold effort Transfer process review

* Representative, not exhaustive CCC, Capacity Command Center; OR, operating room.

Figure 4: This timeline illustrates key milestones in the development of the Capacity Command Center at the Johns Hopkins Hospital.

As one of its first tasks, the steering committee defined the role of the CCC medical director. The notion of a medical director has particular salience at an academic medical center where the physician staff are employed by a School of Medicine independent of the hospital. For this reason, the CCC must operate with lines of accountability that extend across both the university and the health system. A medical director with a faculty appointment serves as a liaison to department directors and a leader for physician change. The medical director shapes strategic and operational decisions, bringing frontline perspective and highlighting potential downstream effects on patient care. This role also engages in day-to-day decisions in the CCC, such as adjudicating disputed patient bed assignments and participating in discussions about complex transfers.

A core leadership group for the CCC meets weekly and drives strategic and operational initiatives. It includes the administrative and medical leadership of the CCC as well a dedicated data analytics team and a group of clinical department representatives (Figure 3). The capacity management leadership team now reports directly to the executive leadership of the organization, meeting on a regular basis to discuss issues of capacity, patient flow, and patient demand patterns. Capacity management is no longer a project but is now a function within the hospital organizational structure.

PLANNED EVALUATION AND NEXT STEPS

Over the past several years, we've built infrastructure and capabilities to actively manage capacity. Key milestones and pivots are highlighted in Figure 4. The primary focus of the CCC continues to be expediting patient care through operational excellence.

Early data are encouraging. At the highest level, we've improved subcycle times and allowed our flagship hospital to increase from 85% to 92% occupancy while decreasing patient delays. For instance, ED boarding with Department of Medicine inpatient beds at 92% occupancy was previously 9.7 hours and is now 6.3 hours (Figure 5). Discharges before noon increased modestly in Medicine and Neurosciences (Appendix 1, available in online article). Likewise, since the launch of a major initiative in November 2017, the number of OR holds has steadily decreased in the context of a constant case volume (Appendix 2, available in on-

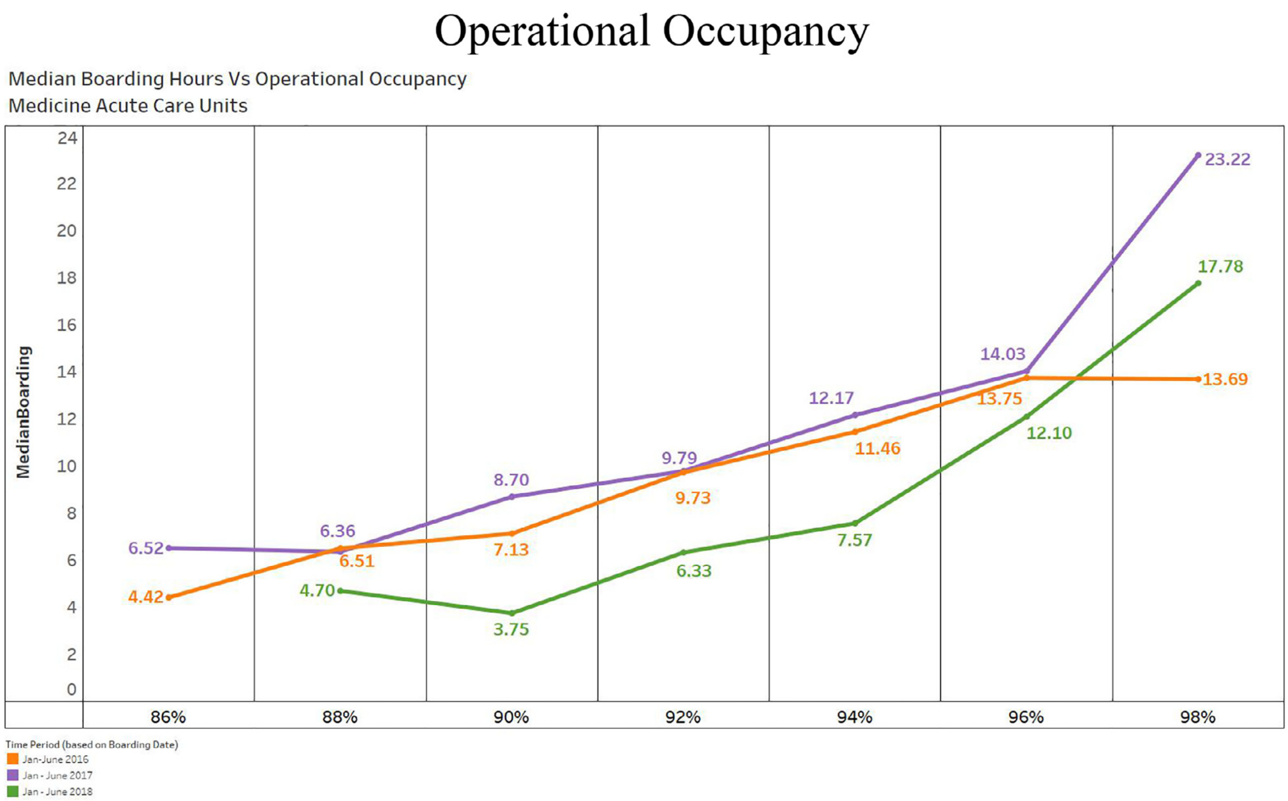


Figure 5: This chart shows the operational occupancy (occupied beds/available beds) vs. median boarding hours (time from request for admission bed to ED departure) for patients admitted to the Department of Medicine. Average operational occupancy for the Department of Medicine at the Johns Hopkins Hospital in fiscal year 2018 was 95%. Inpatient length of stay for the Department of Medicine during these three periods was relatively constant to increased at 5.3 days, 5.5 days, and 5.7 days, respectively. ED, emergency department.

line article). Though our demand still exceeds our capacity, it is estimated that the capacity optimization efforts have added the equivalent capacity of opening 13 to 15 additional beds. It is difficult to know which elements of this effort have had the strongest impact, but transparency, visibility, and accountability for subcycle times and operational metrics have been paramount.

The next frontiers for the Judy Reitz Capacity Command Center at the JHH are (1) channeling the centralized expertise and data into the creation of a daily schedule for inpatients, (2) developing additional tools to optimize resource utilization and productivity, (3) pioneering the integration of predictive *clinical* analytics into the CCC, and (4) strategically harmonizing specialty capacity and programming across the health system. Efforts are also ongoing to distribute the powerful tiles on the Wall of Analytics to other areas of the hospital.

CONCLUSION

We describe here the design and elements of the Judy Reitz Capacity Command Center. Key elements borrowed from command centers in other industries include strategic colocation of teams, automated visual displays of real-time data providing a global view, predictive analytics, standard work and rules-based protocols, and a robust governance structure with guiding tenets. We built our command center with three primary goals—reducing ED boarding, eliminating OR holds, and facilitating transfers in from outside facilities—but the command center infrastructure has the potential to improve hospital operations in many other areas.

Acknowledgments. The authors wish to acknowledge the support of Carrie Price, Welch Medical Library Clinical Informationist, in the preparation of this manuscript.
Conflicts of Interest. All authors report no conflicts of interest.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jcjq.2018.11.006.

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