Traditional Measures of Hospital Utilization May Not Accurately Reflect Dynamic Patient Demand: Findings From a Children’s Hospital

OBJECTIVES: Hospital crowding adversely affects access to emergent and elective care, quality and safety, patient and staff satisfaction, and trainee education. Reliable and valid measurements are crucial to operational planning and improvement, but traditional measures of hospital utilization may not accurately describe dynamic demand at hospitals. The goal of this study was to determine how effectively traditional measures express demand for hospital services and to describe the dynamic nature of patient flow in children’s hospitals compared with alternative measures.

METHODS: This was a retrospective administrative data review conducted at an urban, tertiary care children’s hospital. A total of 28,045 inpatients (22,310 from fiscal year 2008 and 5,735 from 2 months in the fall of 2009 during the H1N1 influenza surge [October 16, 2009–November 18, 2009]) were reviewed. Admission-discharge-transfer data were abstracted from a total of 14 months (1 fiscal year and a separate 2 months including an influenza surge). Hourly hospital census and occupancy were determined. Measures of mean and median length of stay (LOS) were compared. Turnover was calculated by summing admissions, discharges, and interunit transfers. Coefficient of variation (SD/mean) was used to describe variation.

RESULTS: Midnight occupancy was generally closer to minimum occupancy than peak. Peak was usually between 10 AM and 12 PM and was a mean of 4% points higher than midnight (but as large as 13% points). Median LOS was 58% shorter than average LOS. There was a high level of turnover, and patient-days did not express the wide variation in how demand was generated by day of week.

CONCLUSIONS: Traditional metrics for hospital utilization do not accurately express the true extent and dynamic nature of patient flow and inpatient demand at a children’s hospital. Hospitals and government regulatory agencies should consider additional means of measuring utilization to accurately determine demand, including its variation, and thus assist in budgeting, staffing, and capacity planning.

INTRODUCTION
Hospital-wide patient flow issues, including impact on safety, quality, surge capacity, and education, are significant concerns to health care professionals, health system administrators, policy makers, and patients. Valid measurement is the key to management and improvement, but traditional measures of hospital utilization may not accurately reflect demand placed on hospitals and their staffs. Specifically, midnight census, average length of stay (LOS), and patient-days

KEY WORDS
bed occupancy, hospital organization and administration, crowding, pediatrics

ABBREVIATIONS
ADT: admission-discharge-transfer
CV: coefficient of variation
LOS: length of stay

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Dr Fieldston and Ms Jayaraman had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Dr Fieldston was responsible for study concept and design; Dr Fieldston, Ms Ragavan, Ms Jayaraman, Dr Pati, and Dr Metlay provided analysis and interpretation of data; Dr Fieldston and Ms Ragavan drafted the manuscript; Dr Fieldston, Ms Ragavan, Dr Pati, and Dr Metlay provided critical revision of the manuscript for important intellectual content; Ms Ragavan, Dr Fieldston, and Ms Jayaraman conducted the statistical analysis; and Drs Fieldston, Metlay, and Pati provided study supervision. The content is solely the responsibility of the authors and does not necessarily represent the official views of the Children’s Hospital of Philadelphia, the University of Pennsylvania, or the Robert Wood Johnson Foundation. Address correspondence to Evan Fieldston, MD.

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may not convey the dynamic nature of actual daytime demand at hospitals, particularly high-turnover children’s hospitals.17 Many of these measures are reported to hospital leaders, boards of trustees, and state regulatory agencies. These forms of aggregated data, particularly when averaged, may not be accurate measures of true demand for hospital beds, leading to mismatches of capacity.18 More accurate estimation of demand for hospital beds should enable planners and leaders to build and staff beds more efficiently, particularly seeking to have appropriate capacity to accommodate typical daily peak, seasonal variations, daily dynamic turnover, and surges. Alternative measures that may convey operational demand more effectively include peak daily census, median LOS, and variation in patient activity.

In this study, our goal was to describe easily derived alternatives for measuring hospital utilization that may better reflect dynamic demand and variability and compare those with traditional measures over 1 year, as well as during a period of surge in the 2009 H1N1 influenza pandemic to test the these measures at a critical point in time.

METHODS

Data Source

This retrospective administrative data review was performed with admission-discharge-transfer (ADT) data for inpatient admissions from 1 urban, tertiary care children’s hospital for 1 fiscal year (2007–2008), as well as for 2 months in the fall of 2009 during the H1N1 influenza surge (October 16, 2009–November 18, 2009) to determine the way traditional measures estimate demand and capacity during a particularly crowded time period (the type of time during which there is concern that traditional measures may not perform well).18,19 The data set included time stamps of date and time of arrival on an inpatient unit and departure from it, as entered by the unit clerk in the computerized ADT system (Epic Systems Corporation, Madison, WI). All patients were registered by registration/admission office staff as "emergent," "urgent," or "elective" (hereafter referred to as "scheduled") at or before admission. Because only 200 patients were classified as urgent, these patients were recorded for analysis as emergent. During the H1N1 surge, PICU occupancy levels and available beds were also analyzed. From the hospital’s bed management office, we obtained the number of beds available each day. From the financial office at the hospital, we obtained the traditional statistic of patient-days by month and by year.

Definitions

Traditional measures of hospital utilization included midnight census and occupancy, average LOS, and monthly or annual patient-days. Midnight census is the count of patients in the hospital at a designated time. In this study, census was calculated for each hour of each day by applying an SAS macro (SAS Institute, Inc, Cary, NC) to the time stamps associated with patient visits, and midnight, peak, and minimum census figures were extracted. Hospital capacity refers to the number of available beds for patients. Occupancy is census divided by number of beds available. In this study, LOS was calculated by subtracting the admission date and time from the discharge date and time using the recorded time stamps of patient visits. Similarly, PICU LOS was calculated by subtracting PICU admission date and time from PICU discharge date and time. Average LOS is the mathematical mean of LOS for all patients and can be calculated with exact number of hours (present study) or integers of days. Annual patient-days is the sum of each daylong interval (midnight crossings) that patients are in the hospital over a time period but does not include the day of discharge (except for admissions lasting <1 day, which count as 1).

Alternative or additional measures in this study included peak daily census and occupancy (based on maximum census achieved in each 24-hour day). Median LOS was calculated for all patients, with time stamps referenced as noted earlier. To evaluate variability in how hospital activity was generated by day of week, we calculated patient-days generated according to day of admission by multiplying the average LOS (using exact hours of inpatient stay) for each day of the week by the number of patients admitted on that day of the week for patients with LOS ≤7 days (84% of patients). We limited the patients to those with an LOS ≤7 days because patients with a longer LOS skew the mean LOS upward, and therefore using the mean LOS for all patients would not be as helpful in representing patient activity in the hospital generated by each day of the week. To confirm the pattern remained similar, we also analyzed with LOS up to 30 days. To assess variability, we calculated coefficient of variation (CV) (SD/mean) because it is a useful tool when samples sizes are different (such as emergent versus scheduled admissions).20 We assessed variability in 2 ways: by admission type and by time periods (variation by day over the
week and variation by month over the year). When assessing variability over the week, we included 2 measures: one that includes weekends, and one that does not.

Occupancy was determined by dividing census over number of available beds (based on an average number of beds available for each month). The risk of being over a given occupancy threshold (eg, 85%, 90%, 95%) was determined by calculating the percentage of days that occupancy was greater than that threshold. The risks calculated using peak occupancy were then divided by those calculated using midnight occupancy to determine relative risks.

Statistical analysis was performed in SAS 9.2 (SAS Institute), Stata 10.0 (StataCorp, College Station, TX), and Microsoft Excel (Microsoft, Redmond, WA). This study was approved by the Human Subjects Committee of the hospital’s institutional review board.

RESULTS

For the fiscal year (July 1, 2007–June 30, 2008), 22,310 inpatient admissions were included, with 4957 (22.2%) coded as scheduled and 17,353 (77.8%) coded as emergent. Fifty-seven percent of admissions were from the emergency department, 31% by physician referral, and 12% were direct admissions (emergent transports). Among emergent patients, 81% were discharged from a medical service, 11% from a surgical service, and 8% from a critical care unit (pediatric, cardiac, or neonatal). Among scheduled patients, 47% were discharged from a medical service, 49% from a surgical service, and 4% from a critical care unit. Variation in number of admissions per day was high over 7 days of the week (CV 23.7%), but it was lower for weekdays only (6.3%). Monthly variation was 8.1%.

Median LOS (2.3 days) was 58% shorter than average LOS (5.5 days) (Table 1). Half of all patients stayed <3 days and only 15% stayed >1 week, but LOS had wide statistical variation (SD 12.9 days; CV 234%), driven mostly by the skewed distribution of long-stay patients, particularly those in the NICU (n = 769; average LOS 19.9 days; SD 30.1 days).

Overall, for the whole year, daily peak occupancy was 4% points higher than midnight occupancy (85% vs 81%), but the difference was as large as 13% points. The contrast of midnight, minimum, and maximum occupancy on a daily basis in 1 month (Fig 1) illustrates how census ebbs and flows but also follows a consistent pattern. The absolute divergence between midnight occupancy and peak occupancy was larger during busier days of the week and times of the year. Midnight occupancy was generally closer to minimum occupancy than peak over the year (Fig 2). As a result, using peak instead of midnight occupancy revealed a greater risk of exceeding 85%, 90%, and 95% occupancy thresholds (Fig 3). The relative risk of being over these thresholds was higher at peak than at midnight: 1.2 for 85%, 1.5 for 90%, and 3.6 for 95%.

### TABLE 1 Traditional Versus Alternative Measurements of Hospital Inpatient Activity Over 1 Year

<table>
<thead>
<tr>
<th>Desired Information</th>
<th>Traditional Measure</th>
<th>Alternative/Additional Measures</th>
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<tbody>
<tr>
<td>Inpatient occupancy (%) based on census LOS*</td>
<td>Midnight occupancy: 85% (annualized) Average LOS: 5.50 d</td>
<td>Peak daily occupancy: 89% (annualized) Median LOS: 2.29 d Percent patients with LOS: 13% ≤24 h, 20% ≤27 h, 43% ≤2 d, 61% ≤3 d, 76% ≤5 d, 84% ≤7 d</td>
</tr>
<tr>
<td>Variability in number of admissions</td>
<td>Not traditionally reported</td>
<td>CV: 8.1% by month CV: 23.7% by day of week CV: 6.3% by weekday</td>
</tr>
<tr>
<td>Activity of the hospital</td>
<td>Patient-days (annual total): 130088</td>
<td>Patient-days generated by day of admission Weekdays only (mean ± SD): 7226 ± 441 d Weekdays only (mean ± SD): 6429 ± 1410 d</td>
</tr>
<tr>
<td>Variability in activity</td>
<td>Not traditionally reported</td>
<td>Weekdays only: All admissions CV: 6.3% Emergent CV: 10.3% Elective CV: 5.2% Weekdays + weekends: All admissions CV: 21.9% Emergent CV: 9.6% Elective CV: 6.7%</td>
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*For these calculations, LOS is calculated with exact admission and discharge times, not intervals of days.
Including weekends and holidays in monthly mean occupancy figures for any time of day lowered them by up to 7% points.

To understand patterns of occupancy, we examined it hourly and found that only 9.9% of daily peaks occurred between 10 PM and 2 AM (the time including midnight). Peak most often occurred midday: 64% of peaks were between 10 AM and 12 PM and 11% were between 12 PM and 2 PM.

For October–November 2009, which included the H1N1 surge, there were 5735 inpatient admissions (80.7% emergent and 19.3% scheduled). As measured by average daily census at midnight, the months of October and November hit record levels on individual days for the hospital, yet averages of midnight census (including weekends) do not portray the true extent of daytime demand. An absolute difference of 10% between midnight occupancy and peak occupancy represents a difference in 46 beds. Thus, 20 to 40 more beds per day seemed to be available using midnight figures than was the reality at the times the beds were needed at midday on weekdays (Table 2). Even more specifically, the PICU, a location that handled large numbers of patients, seemed less busy when using midnight instead of peak figures. The proportion of the time the PICU spent >95% full is more marked by using peak census than midnight or looking only at weekdays.

Patient-days generated by day of week of admission demonstrated variability not reported by annual patient-days, with a mean of 6429 patient-days by day of week (for patients with LOS ≤7 days and including weekends), with an SD of 1410 and CV of 21.9%. The high variability reflects the decrease in scheduled admissions and direct physician-referral admissions on weekends (Table 1, Fig 4). In this construct, Mondays and Tuesdays alone generated 44% of the scheduled (elective) patient-days generated by day, with a pattern of many patients having overlap hospitalization time by midweek. When including patients with LOS <30 days (n = 21 661; 97.1% of admissions), mean patient-days generated by day increased to 11 932

FIGURE 1 Daily occupancy for 1 month measured 3 ways (March 2008).
emergent patients had a CV of 14% on patient-days generated by day of week, whereas scheduled patients had a CV of 64% (Fig 5).

**DISCUSSION**

This study reveals that traditional measures of hospital utilization (average LOS, midnight census, and total patient-days) do not accurately express the dynamic and variable nature of demand for inpatient services at a children’s hospital.

Average LOS does not accurately portray the short-stay, high-turnover nature of patients typically seen at children’s hospitals. Median LOS was approximately half of average LOS. From a statistical standpoint, this is not surprising, as LOS cannot have a normal distribution. Hospitalized patients cannot stay a negative time period, and most admissions are at least 1 day long. Patients can stay for very long periods of time, however, creating an extreme skew. LOS and patient volume data serve multiple purposes. One may be at a more global level to convey total utilization, in which case average LOS multiplied by volume yields patient-days. Average LOS is also useful in calculating CV, a good measure of variability. Median LOS cannot be used for either of these purposes. For day-to-day management, however, average LOS may not express the needs of caring for the typical patient. Given the large skew in LOS data, the average (or mean) is not statistically appropriate. The results in this study confirm that the median is a more appropriate measure of the central tendency for LOS at children’s hospitals, particularly to understand the experience of typical patients to match resources to them. More explicitly, the use of average LOS conveys that staff has many days to take care of patients and prepare them for discharge, when in fact half the patients are in-house for ≤2 days.

To augment median LOS, percentage of patients with an LOS of 1, 2, 3, 5, and 7 days could also be reported regularly to help guide hospitals with...
staff and care models. The needs of patients who stay 1 day are different from those who stay 2 to 3 days and even more from those who stay 5 to 7 days or longer. LOS reporting could also include observed to expected LOS ratios, also known as standardized LOS ratios, because these provide a sense of relative efficiency, even if only for internal benchmarking over time at a given institution. Although potentially very valuable, timely calculation of standardized LOS ratios, however, may not be realistic for hospitals due to the computational demands of having an expected LOS based on diagnosis-related groups, age, and severity levels to match with observed LOS values. If feasible, however, LOS measurement to the hourly level, with expected LOS benchmarks to generate standardized LOS ratios, can help hospitals distinguish when an evening discharge is actually an “early” discharge for the next day, as opposed to a late one for the current day.

Midnight census and its derivatives, such as average daily census for a month or year, have been used by hospitals to determine capacity needs, budgeting, and staffing, but it is not clear that this measure captures the full extent of demand for beds or its dynamic nature. In this analysis, average midnight census performed poorly as an indicator of weekday daytime occupancy because it was often closer to the minimum census for the day than the peak census, especially when averaged over all days of a month (thus including lower-census weekends), as

| TABLE 2 Traditional Versus Alternative Measurements of Occupancy During the H1N1 Surge of Fall 2009* |
|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Measurement                                      | All Days                                      | Weekdays Only                                  | All Days                                      | Weekdays Only                                  |
| Mean hospital midnight occupancy versus daily peak occupancy, % | 86 vs 89                                      | 89 vs 90                                       | 89 vs 92                                       | 92 vs 93                                       |
| Hospital days >90% occupancy at midnight versus peak, % | 34 vs 43                                      | 47 vs 53                                       | 53 vs 68                                       | 71 vs 83                                       |
| Hospital days >95% occupancy at midnight versus peak, % | 7 vs 13                                       | 9 vs 19                                        | 13 vs 24                                       | 17 vs 33                                       |
| Mean PICU midnight occupancy versus daily peak occupancy, % | 90 vs 94                                      | 91 vs 95                                       | 94 vs 97                                       | 95 vs 96                                       |
| PICU days >90% occupancy at midnight versus peak, % | 62 vs 74                                       | 72 vs 84                                       | 76 vs 94                                       | 88 vs 96                                       |
| PICU days >95% occupancy at midnight versus peak, % | 30 vs 54                                       | 48 vs 75                                       | 44 vs 68                                       | 57 vs 74                                       |
| PICU days >100% occupancy at midnight versus peak, % | 2 vs 8                                         | 7 vs 7                                         | 3 vs 15                                        | 8 vs 12                                        |

Differences of 10% points or greater are in bold.
*Surge dates were October 16, 2009–November 18, 2009.
has been previously described.\textsuperscript{18} Monthly and annual averages are known to overestimate available surge capacity due to inclusion of weekends and holidays,\textsuperscript{18} and the use of midnight as the base measure for averaging seems to contribute to this misestimation. The fact that crowding is often reported (at least for some days of the week), especially in children’s hospitals,\textsuperscript{12,22–24} suggests that the values of hospital occupancy used for planning are not properly reflecting the reality of activity. Although hospitals may find a consistent correlation between their midnight census and peak census that would allow use of the former for capacity-planning and budgeting purposes, electronic data systems make using a second-best proxy unnecessary. Moreover, the correlation between midnight and peak census may not hold consistently and it would involve more analytic and operational work to evaluate the relationship than to simply report occupancy at the busiest time of day. Electronic ADT systems could be programmed to report peak census or occupancy for each day in real time to facilitate operational planning. Alternatively, since peak occupancy occurred consistently at midday (as inbound and outbound patients overlapped), if repeated in other settings, hospitals may have access to a consistent time for measurement that would be a more accurate reflection of demand for beds than midnight. Separating weekdays from weekends can also be useful to ensure an accurate portrayal of occupancy, especially for hospitals with pronounced declines in weekend census. Depending on the nature of their pattern of admissions and census, attention to both peak census and dynamic changes can help hospitals better match staff to workload, rather than using averages and adjusting empirically.

Specifically evaluating the performance of traditional versus alternative measures during a high-demand period is also illustrative, as was possible for the influenza A H1N1 pandemic in the fall of 2009. Like other hospitals, The Children’s Hospital of Philadelphia saw a significant increase in ambulatory, emergency department, and inpatient volume.\textsuperscript{23,25} By relying solely on traditional measures of demand, however, the extent of stress on the system is not apparent. Peak census expresses the demand in more detail than midnight census, not only for the hospital as a whole, but also for individual parts of it, such as the PICU.

Although the measure of patient-days expresses the total business that the hospital does, it does not convey the pattern of how business is generated, which is important to staffing and understanding how capacity is used. Evaluating patient-days generated by day of admission and evaluating the variation using CV effectively shows the variability in how the hospital generates its business. The patient-days generated by day of admission metric directly shows how variability in admissions and LOS generates a high proportion of the hospital’s business early in the week and much less on weekends (Fig 4). Patient-days and simple averages may be appropriate if there was consistent and smooth flow of patients, but the artificial variability of scheduled admissions\textsuperscript{26} and the wide
range of LOS mean that using averages to describe patient flow is not statistically appropriate. Thus, these measures do not supply information about how resources are being used or if demand (revenue) is being matched to capacity (costs) in a reasonable manner.24,27

Although not considered in this study, patient care and flow occur at the unit level, so microsystem measurement may reveal additional capacity demand insights. Specifically, measuring total turnovers (admissions, discharges, and interunit transfers) at the unit level would express key information on workload for clinical and nonclinical staff. Although the term “bed turns”28 (admissions divided by functional beds) has been advanced as an indicator of throughput, or the number of patients who move through the hospital in a given time period, it measures how many times a bed is used rather than the workload experienced by the staff in caring for patients, which should be considered at admission, interunit transfer and discharge.

This study has several limitations. First, only 1 children’s hospital was analyzed so the findings may not be generalizable to other settings. Nonetheless, the methods are transferable for other hospitals to evaluate their own patterns. Second, census and LOS were generated based on time stamps of arrival to and departure from hospital units, so entry errors would influence those derived values. The most likely direction of this bias would be toward a higher census or longer LOS, as computer entry of departure from the floor is more likely to be delayed than arrival on the floor. Third, to calculate percent occupancy, we used an average bed capacity for each month, not varying that by day. The direction of bias would vary for this calculation. In addition, the bed capacity denominators were beds-in-use as reported by the bed management office without confirmation that all beds were staffed. In this case, inclusion of unstaffed beds would cause our estimates of occupancy to be lower than in reality, as our denominator would be too high.

CONCLUSIONS

Traditional measures of hospital utilization, if used as the basis for capacity planning, staffing, and budgeting, may not convey dynamic and variable aspects of demand. As an addition to the traditional measure of average LOS, median LOS would be more useful (and statistically appropriate) when evaluating duration of hospitalization of typical patients. Use of midnight census can lead to undercounting demand for beds for emergent and scheduled admissions. It also provides an underestimate of the availability of beds for surge capacity to handle disasters.18 To optimally manage occupancy, hospitals and ADT system vendors should build systems that automatically report peak census and occupancy information for each 24-hour period and/or a routine daytime count that more accurately reflects demand for beds. The use of patient-days generated by using day of admission allows for hospitals to better evaluate how they are generating business and contributing to occupancy over the week. Finally, hospitals should track variation in admissions and occupancy with measures such as CVs. Ultimately, better measures that are linked to evidence-based management should lead to improved access to and quality of care at hospitals.

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REFERENCES

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