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Understanding Demand and Capacity Mismatch in an Academic Emergency Department Using a Staircase Model of Provider Capacity and Staggered Shift Start Times

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☐ Abstract—Background: Staffing and provider capacity are essential components of emergency department (ED) throughput. Patient flow is dependent on matching patient arrivals with provider capacity. Current models assume a static rate of patients per hour for providers; however, this metric has been shown to decrease throughout a shift in a pattern we describe as a staircase. Objective: We sought to analyze the demand capacity mismatch based on both a static and staircase model of resident productivity. We then suggest a new staggered staffing model that would improve flow in the ED. Methods: This was a retrospective analysis of patient demand and productivity, analyzing both static and staircase models of provider capacity. An alternative staggered shift model was then suggested, and a 2-sample *t* test was performed to assess if a new model reduces the amount of demand/capacity mismatch. Results: Seventeen thousand five hundred twenty data points were analyzed over the 2-year interval, comparing the difference between actual patients placed into a treatment space at each hour and projected resident capacity based on the staircase model, using both the existing schedule and a new staggered schedule. Mean absolute values for the disparity in coverage was 2.69 (95% confidence interval 2.65–2.72) for the staircase scheduling model, and 2.14 (95% confidence interval 2.12–2.17) when staggering provider start times. The mean difference between these data sets was 0.54 (95% confidence interval 0.52–0.57; $p < 0.0001$). Conclusions: Academic EDs may find value in using a staircase model to analyze provider capacity because it is more reflective of actual capacity. EDs may benefit from visualizing their capacity curves to identify mismatches and staggering resident shifts to improve throughput and flow.

☐ Keywords—efficiency; emergency service, hospital; operations; workflow; workforce

Introduction

Staffing models and provider capacity are essential components of emergency department (ED) throughput. Administrators at every ED—both academic and community—must design staffing patterns to optimize timeliness and efficiency of patient care. Many smaller community EDs use single coverage with only 1 physician on at a time. Additional patient demand is often supplemented by a swing shift or an advanced practice provider (APP) during the highest-volume periods of the day. As an ED's annual visits increase, more provider coverage becomes necessary and the variability of staffing models increases. Even low-volume EDs must have 5 full-time equivalents on staff to provide 24-hour, 7 day a

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week coverage and account for vacation (1). Once volume is >20,000 yearly visits, EDs can estimate needing approximately 2.8 additional full-time employees for every 10,000 additional patient visits (1). Even with a larger workforce, there are often still prolonged wait times and long door-to-provider metrics. We sought to analyze the current staffing structure at a large academic center, identify the mismatch between patient demand and provider capacity, and compare it with a novel staircase model of resident capacity with a staggered shift structure.

Most EDs are staffed to match the number of patient arrivals per hour with the average number of patients seen by a provider per hour (i.e., 2 patients/hour) for the duration of a shift. The total of the capacity to see new patients in any given hour should ideally match the hourly patient arrivals to a treatment space. To analyze this relationship, one can graph new ED bedded patients per hour and overlay provider capacity (total patients per hour) on top of the hourly patient arrivals to a treatment space (2). Using this data visualization method, administrators can assess when the largest number of bedded patients occur and allocate resources accordingly to ensure adequate physician/APP capacity.

It is important to note that this model assumes a constant rate of patients per hour for providers. While this assumption simplifies modeling, it is not a realistic representation of provider capacity to see new patients throughout the length of a shift. Recent studies have shown that patients evaluated per hour decreases in a stepwise manner throughout an individual shift, which we term a staircase pattern (3,4). By applying this staircase model of provider capacity, we sought to reassess the demand and capacity mismatch in our department and how it compares to the static (or constant) patients per hour model.

Using an assumption of constant patients per hour, our ED should have excellent coverage. However, when actual patient per hour data are applied, we discover that a queue frequently builds between the hours of 7 PM and 11 PM. This queue leads to increased door-to-provider time. We hypothesize that this discrepancy is a result of normal behavior as providers see fewer patients approaching the end of their shift at 11 PM. In this study, we sought to analyze our departmental flow with our novel staircase model and then stagger provider shifts to create a novel staffing model to optimize patient flow in our ED.

Materials and Methods

This was a retrospective study at an academic ED with approximately 55,000 annual visits. Daily resident staffing includes 5 emergency medicine (EM) postgraduate year (PGY) 2 shifts (EM2), 4 EM PGY1 shifts (EM1), and 4 PGY1/PGY2 off-service resident shifts (off-service) from various specialties, such as internal medicine, anesthesia, and obstetrics/gynecology. The resident shift schedule is shown in Table 1.

Table 1. Current Shift Structure

Type of Resident	Shift Start Time	Shift End Time
EM2	7 am	3 pm
EM1	7 am	3 pm
EM2	10 am	6 pm
Off-service	10 am	6 pm
Off-service	12 pm	8 pm
EM2	2 pm	11 pm
EM1	2 pm	11 pm
Off-service	2 pm	11 pm
EM1	3 pm	11 pm
EM2	5 pm	2 am
Off-service	5 pm	2 am
EM2	11 pm	7 am
EM1	11 pm	7 am

EM1 = emergency medicine postgraduate year 1; EM2 = emergency medicine postgraduate year 2; off-service = postgraduate year 1/2 off-service resident.

We assigned each resident category a standard number of patients seen per shift based on previous data analysis for that group of residents: 14 for an EM2, 10 for an EM1, and 8 for an off-service resident. EM3 residents are present for all 24 hours of the day, but they serve primarily in a supervisory role. Aside from occasions when high volume necessitates it, both the EM3 residents and attendings do not see patients independently. These productivity data are based on studies in our own ED suggesting that EM2s see a mean of approximately 12 patients per shift and off-service residents see a mean of approximately 6.5 patients per shift (3,5,6). EM1s have the most variability as they progress through their training, starting off the year at a mean of around 7 patients but rising to 11 by the end of the year. Based on these data, we used the approximate 75th percentile to determine the estimated capacity for each type of resident.

We collected patient arrival data from July 1, 2017 to June 30, 2019 and graphed this by hour of placement into a treatment space in the ED. We overlayed provider capacity based on the current shift schedule using a static patient per hour model (i.e., 1.75 patients/hour for 8 hours for an EM2) (Table 1). We calculated the demand/capacity mismatch, defined as the total number of patient arrivals to a treatment space each hour that exceeded provider capacity during that same timeframe. This study design was approved by our institutional review board with a determination of exemption.

To build the staircase model we redefined provider capacity based on the staircase patient per hour assump-

Figure 1. Emergency medicine postgraduate year 2 (EM2) capacity, static vs staircase, 14 total patients.

tions (see Figure 1 for an example of EM2 resident productivity). In this model, each resident type saw a higher volume of patients earlier in the shift, decreasing in a stepwise manner and not seeing patients for the last hour of the shift. This shape was based on previous data for the number of new patients seen during each hour of a shift. Data—including means, medians, and interquartile ranges—were available for EM1 and EM2 residents. The theoretical capacity for EM1/EM2 resident hour was determined using the aforementioned total patient per shift values. Data of patients per shift were available for off-service residents, but data on patients by hour of shift were not previously obtained, so the shape of the staircase was determined by consensus of the authors using conservative patient per hour assumptions given off-service resident lack of familiarity with ED protocols and more junior PGY level. Afterward, we recalculated the demand/capacity mismatch based on the staircase model of productivity and the current resident schedule to more accurately reflect the actual flow of our ED.

To better match demand and capacity, we adjusted shift start times so new residents started in a staggered fashion throughout the day rather than the current model where groups of residents start at specific times in order to reduce intervals when there are large number of patient arrivals to treatment spaces and low provider capacity. EM2 coverage was required for all 24 hours of the day. Adjustments were made and the patient gap was recalculated to determine the schedule that optimally reduced the difference between demand and capacity.

Results

Our ED averaged 150.66 arrivals per day over the study period. Based on our model, on an average volume day, residents would see 142 patients per day, leaving an expected gap of 8.66 patients to be made up by an attending physician or PGY3 seeing patients primarily. This assumes a perfect match between demand and capacity and is simply reflective of total patients a day and total predicted provider capacity for the day. It does not consider lost capacity because of provider times when there are fewer patients available than capacity to see them such as during times with low patient arrivals, such as parts of the overnight shift. Perfect matching would result in 94.25% of patient demand being met by the standard resident capacity.

Using the static patient per hour model and the existing staffing model, the demand/capacity curve demonstrated a gap of 18.70 patients that would need to be seen by the attending or EM3—10 patients higher than the minimum of 8.66 (Figure 2). This number was calculated by adding the total daily arrivals to treatment spaces per hour that exceeds the presumed capacity (green line). Areas where the capacity line is above the number of bedded patients indicate potential times of wasted resident productivity. In this model, only 87.59% of patients are adequately matched with capacity based on the standard schedule and capacity assumptions.

When the capacity-based staircase model was used, the gap increased to 27.71 patients with a significant amount of wasted capacity with the arrival of new teams, and excess patient demand at the end of the evening shift before the arrival of the overnight team (Figure 3). This model was most reflective of the observed long times from bed placement to provider contact during this time of the day. Only 81.61% of the daily 150.66 patients were accounted for by the primary staffing structure.

When maintaining the staircase model and staggering the shifts, this curve was smoothed out and the patient gap was decreased by 49% to 14.24 patients, with 90.55% of

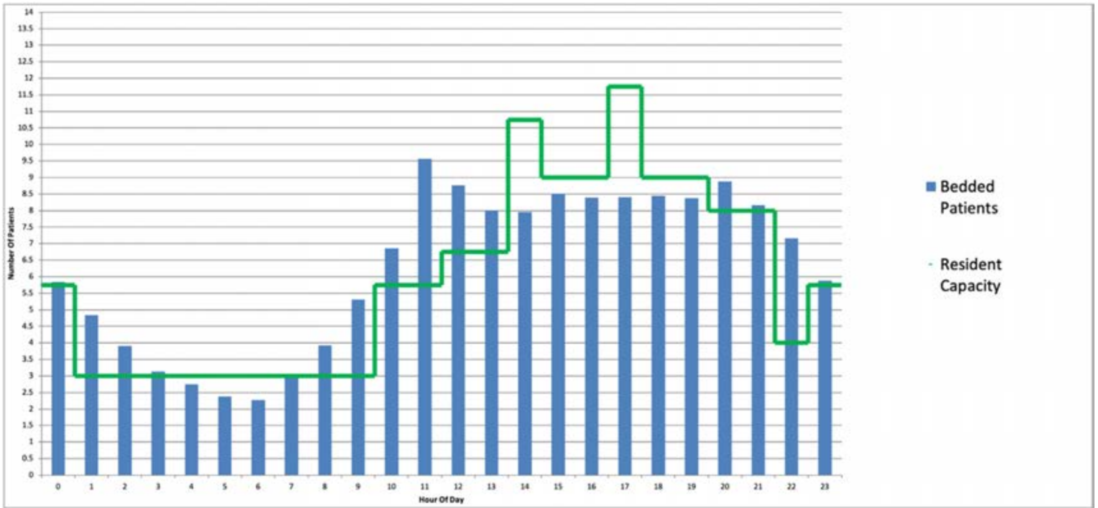

Figure 2. Static resident productivity with standard schedule vs bedded patients per hour.

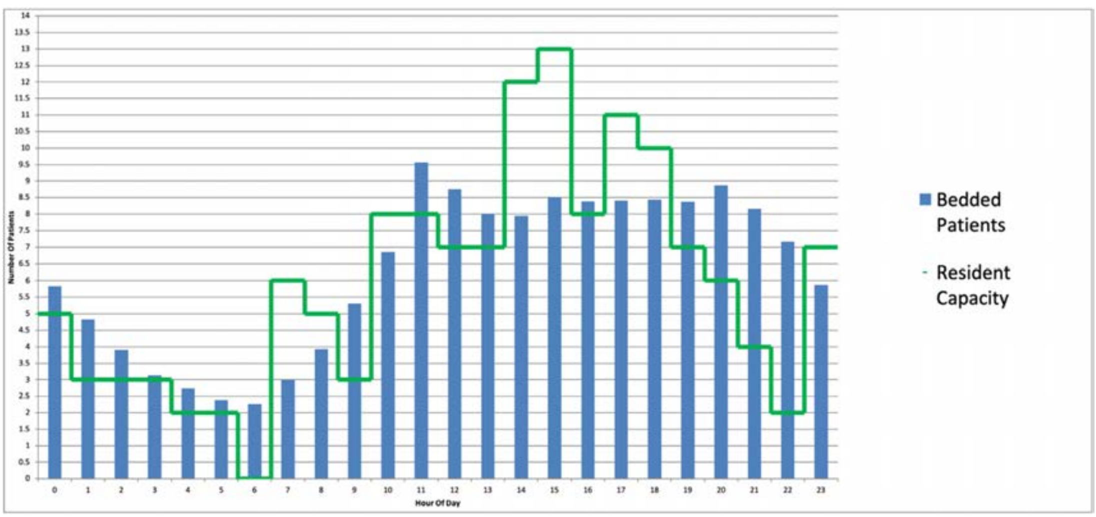

Figure 3. Staircase resident productivity with standard schedule vs bedded patients per hour.

the patient volume now accounted for with standard resident shifts (Table 2 and Figure 4). This is an absolute increase of 8.94% of daily patient volume (around 13 total patients) that can now theoretically be seen by the regularly staffed residents, thereby decreasing the burden on the EM3 and the attending physician.

We analyzed all the hours within the study period over 2 years for a total of 17,520 data points. We compared the difference between the number of actual bedded patients at each hour with both the current resident capacity and the projected resident capacity of the modified staggered schedule. We found the mean of the absolute values for the disparity in coverage was 2.69 (95% confidence interval [CI] 2.65–2.72) for the standard schedule model, and 2.14 (95% CI 2.12–2.17) for the staggered schedule model. The mean difference between these data sets was 0.54 (95% CI 0.52–0.57). Using a 2-sample t test with unequal variance we found a statistically significant difference ($p < 0.0001$) between the standard and staggered schedule models, suggesting that the staggered model reduces the amount of demand/capacity mismatch.

Discussion

Accurate and efficient staffing is critical to achieving smooth throughput in an emergency department. The complexity of this increases significantly in EDs that require more than single provider coverage. At academic centers, where residents are the primary workforce, this becomes further complicated given different types of providers, work hour constraints, and educational require-

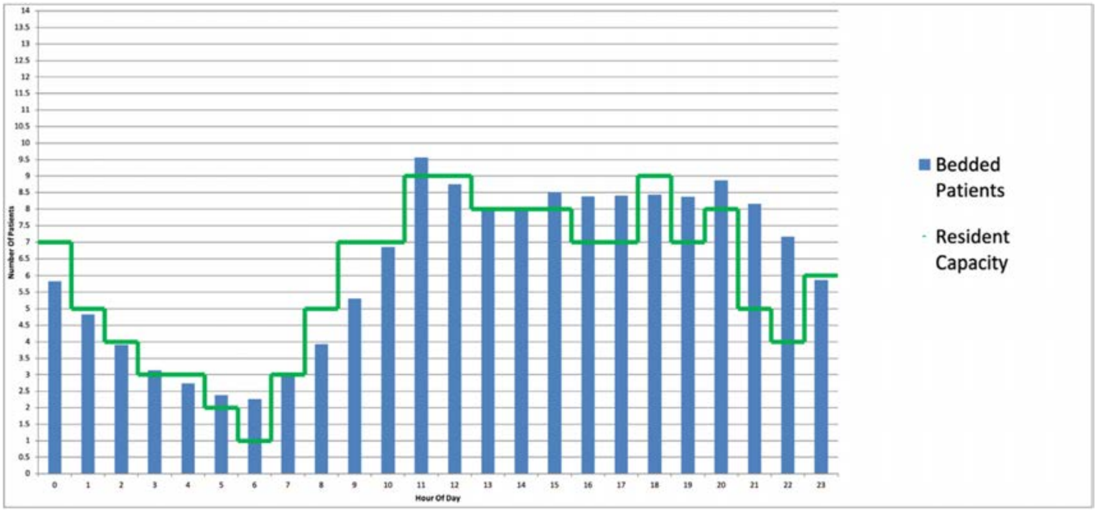

Figure 4. Staircase resident productivity with staggered schedule vs bedded patients per hour.

Table 2. Staggered Shift Structure

Type of Resident	Shift Start Time	Shift End Time
EM2	7 am	3 pm
Off-service	8 am	4 pm
EM1	9 am	5 pm
Off-service	10 am	6 pm
EM2	11 am	7 pm
Off-service	12 pm	8 pm
EM2	2 pm	10 pm
EM2	4 pm	12 pm
EM1	6 pm	2 am
Off-service	6 pm	2 am
EM1	8 pm	4 am
EM1	11 pm	7 am
EM2	12 pm	8 am

EM1 = emergency medicine postgraduate year 1; EM2 = emergency medicine postgraduate year 2; off-service = postgraduate year 1/2 off-service resident.

ments. Current modeling techniques used by administrators to allocate staffing can be misleading and require improvement. The primary tools available for staffing are based on static patient per hour assumptions that do not reflect real provider capacity and ED flow. In this study, we developed and tested a novel staircase model to determine whether the mismatch between patient demand and provider capacity could theoretically be reduced.

Previous studies have analyzed common ED models—assessing ways to determine both the number of physician-hours needed as well as compensation rates (7). Other literature has created new models to assess when time and space are limited in a pediatric ED (8). This publication adds to this discussion by suggesting a novel staffing approach and testing its theoretic impact based on data within our ED.

When assuming a static patient per hour productivity, our curve suggests that bedded patients should outpace resident capacity from 8 AM until 1 PM. There is a slight amount of excess resident capacity at 2 PM and 5 PM when there is shift overlap. The remainder of the evening shows capacity matching closely to the average hourly arrivals to treatment spaces (Figure 2).

However, our experience suggests that this is not the true workflow in our academic ED. There is rarely a queue before 1 PM, and as the evening progresses toward the arrival of the overnight team at 11 PM, many patients end up waiting for a provider for a significant amount of time. By redefining an individual resident's patient per hour curve we were able to remodel our ED in a way that more closely approximates reality and is reflective of extended patient wait times experienced in the evenings (Figure 1).

Using the staircase model with the standard schedule, which is a better reflection of true resident capacity, there are multiple points in time where provider capacity exceeds hourly bedded patients, always coinciding with shift start times (Figure 3). This occurs because providers show up fresh at the start of a shift and can handle a higher volume. This represents wasted provider capacity that is not recoverable later in the shift. This well-studied phenomenon helps explain why a late-morning queue predicted by the static model was rarely seen in practice.

As an individual shift progresses and the patients on a resident's workflow require reevaluation and follow-up, it becomes harder to see new patients. Factors such as signed-out patients can increase this burden (9). At the end of the shift, providers often focus on completing work-ups to minimize sign-out tasks to the next team, and will forego seeing new patients. However, if a resident does not see a high volume of patients in the first 2 hours of a shift, that does not mean that same capacity is available during the last 2 hours. This is clearly demonstrated between the hours of 7 PM and 11 PM, when many bedded patients build up until the overnight team arrives at 11 PM. In our model, the amount of excess patient demand totaled 27.71 patients—9 patients higher (approximately 48%) than the static model predicts when residents see a constant number of patients each hour.

Recognizing the theoretical benefits of this new model, we manipulated the resident shift schedule to assess whether we could realize an optimal demand/capacity benefit reflecting actual resident productivity in our ED. We recognized that staggering shifts to avoid multiple residents arriving at the same time and moving some shift starts to the evening would smooth the curve and allow residents with fresh capacity at the beginning of a shift to be optimally matched to a time when it was most needed (Figure 4). Doing so reduced the excess demand by 49% to 14.24 patients compared with 27.71, demonstrating that remodeling individual capacity using a staircase model more optimally matched departmental flow. While staggering shifts has been previously studied to reduce handoffs, this model suggests an additional benefit of better matching actual ED demand with provider capacity (10).

We recognize that while Table 2 represents an optimal shift alignment for improved door-to-provider time and reduced length of stay, overhauling the resident shift schedule at an academic ED has multiple implications beyond maximizing flow and productivity. In the original schedule, multiple residents started and ended most shifts at the same time. This has several benefits: residents are coupled to an attending physician, with whom they staff all their patients for an entire shift; this also allows residents to finish work at the same time and can be important for the team-based dynamics of an ED. In addition, there are factors such as work-hour requirements, time between shifts, and protected educational time that must be accounted for.

Another potential challenge with this novel model is that a staggered schedule makes signing out patients at the end of a shift more complicated. In our ED, the 10 AM to 6 PM shift would naturally sign out to the 5 PM to 2 AM shift, but who to sign out to is less clear with a staggered schedule. Our own experience suggests that before implementing a change the education of both residents and attendings on the new dynamics involving patient handoffs is critical.

Lastly, reducing the biggest mismatch between 7 PM and 11 PM required the creation of a shift that starts in the late evening. This allows for a fresh resident to see these patients early in their shift when productivity is highest. However, a shift from 8 PM to 4 AM will often have lifestyle compatibility concerns. While not truly an overnight shift, it will often be viewed as one by residents. These scheduling dynamics will require collaboration with residency program leadership to ensure that final adjustments will be balanced with off-service requirements and resident wellness.

In addition, resident capacity is not a fixed value, and the model used represents our best projections of how residents see patients from previous data and experience. Residents usually do not see new patients in the last hour of the shift, cleaning up their patient list in preparation for sign-out. This is enabled by overlap with other oncoming residents. This does not apply to the overnight shift where no overlap occurs at 7 AM. If multiple patients arrive at 6 AM, the residents will still often see at least some of them even though we have assumed no patient capacity during that hour. Similarly, if there are extreme circumstances, such as a spike in arrivals for a given hour or multiple critical patients at the same time, residents can stretch their capacity temporarily to meet this demand (11). These fluctuations in resident effort are difficult to account for in the model, which is based on historic average capacity.

Even with the stated limitations and other external factors impacting the final shift schedule, we believe that adjusting our shifts will decrease the patient door-to-provider time by better aligning demand and capacity. There are many potential downstream effects, including better patient safety, improved satisfaction, and reduced length of stay. We think that adopting a staircase model of productivity and staggering shifts will allow other academic EDs to improve overall flow. This modeling is also applicable to high-volume EDs where, similar to residency programs, multiple physicians or APPs are working at the same time and shift start times can be adjusted to better match bedded patient volume.

Limitations

We recognize there are limitations to our model. It is a theoretical concept and may not be fully applicable at other institutions because of different constraints. It is based on experience with a single academic center, which may limit its generalizability given that resident capacity, shift length, and the overall staffing structure may differ at other sites. While our study captures resident capacity based on data from our institution, there may be variability in capacity for which we did not account. Further investigation studying internal validity is needed to assess the model's impact on throughput and demand/capacity mismatch. Impacts of this model to shift schedules at other institutions will require additional studies.

Conclusions

In conclusion, academic EDs should use a staircase model to analyze provider capacity because it is more reflective of reality. EDs would benefit from visualizing their capacity curves to identify mismatches and staggering resident shifts in order to improve throughput and flow.

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Article Summary

1. Why is this topic important?

Staffing and productivity are essential components of emergency department (ED) throughput, and administrators at every ED—both academic and in the community—must decide how to best organize their staffing to ensure the best patient care. Accurately understanding clinician capacity provides the appropriate tools to improve staffing, enhancing ED flow.

2. What does this study attempt to show?

By analyzing provider capacity using a staircase model, we can obtain a more accurate model of ED capacity. This information can then be used to adjust schedules to improve the mismatch between patient demand and provider capacity.

3. What are the key findings?

A staircase model of capacity more accurately describes physician workflow. Staggering shifts may provide significant improvements in demand/capacity mismatches in academic EDs.

4. How is patient care impacted?

Improvement in demand/capacity mismatch should lead to improved door-to-provider times, potentially speeding up access to care for our patients and reducing overall length of stay.