Timeliness and Efficiency

Mapping the 24-Hour Emergency Department Cycle to Improve Patient Flow

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Emergency physicians are increasingly realizing that emergency medical care is "on the clock." For example, core measures developed by The Joint Commission, such as those pertaining to thrombolytic administration or to pneumonia care,[1] and "Pay-for-Performance" initiatives[2] are driving the demand to provide specific treatments in a timely fashion. Research on emergency department (ED) throughput has largely focused on the limited factors that influence length of stay,[3–7] yet it seems intuitive that clinical quality depends on operational efficiency. However, few EDs have access to the necessary data to truly define what goes on in a 24-hour period and what resources are therefore required on an hour-by-hour basis to care for their patients.

It is increasingly recognized that electronic information systems can be used to improve the efficiency of patient flow and capacity management.[8–11] According to VHA data, 44% of the EDs in the United States are using electronic tracking systems, and 56% have dedicated ED information systems.[12] Most EDs, however, still function with information systems that are not fully integrated; that is, data from tracking systems, laboratory and radiology systems, registration and financial information, and other areas vital to ED patient care are not linked in a common ED data repository that can be accessed and quantitatively analyzed. Absent the ability to utilize this information, we will continue to operate with an information deficit.

In the context of an overall quality improvement program, we conducted a study in an effort to improve patient flow. We analyzed ED operations by time of day to

Article-at-a-Glance

Background: Intermountain Healthcare (Salt Lake City), in conjunction with emergency department (ED) staff at LDS Hospital, designed an integrated patient tracking system (PTS) and a specialized data repository (ED Data Mart) that was part of an overall enterprisewide data warehouse. After two years of internal beta testing the PTS and its associated data captures, an analysis of various ED operations by time of day was undertaken.

Methods: Real-time data, concurrent with individual ED patient encounters from July 1, 2004 through June 30, 2005 were included in a retrospective analysis.

Results: A number of patterns were revealed that provide a starting point for understanding ED processes and flow. In particular, ED census, acuity, operations, and throughput vary with the time of day. For example, patients seen during low-census times, in the middle of the night, appear to have a higher acuity. Radiology and laboratory utilization were highly correlated with ED arrivals, and the higher the acuity, the greater the utilization.

Discussion: Although it is unclear whether or not these patterns will be applicable to other hospitals in and out of the cohort of tertiary care hospitals, ED cycle data can help all facilities anticipate the resources needed and the services required for efficient patient flow. For example, the fact that scheduling of most service departments falls off after 5:00 P.M., just when the ED is most in need of those services, illustrates a fundamental mismatch between service capacity and demand.

determine relevant patterns that might affect staffing and operational efficiencies, characterizing for the first time the "24-hour ED cycle." In this article we describe how a homegrown tracking system was designed and integrated into existing functional and robust information systems. The diverse electronic islands of information affecting the ED (for example, registration, radiology, laboratory) were linked, enabling data to be passively transferred from the tracking system into a specialized data repository, the ED Data Mart. Although many health systems have set up large data warehouses for related data, the ED Data Mart is unique as a repository for data relevant to ED encounters obtained from the integrated tracking system.

After two years of internal beta testing on the Patient Track System (PTS; a single module of an enterprise-designed comprehensive ED information system [EDIS]) and its associated data captures, the linked data were mined to explore patterns of ED census, acuity, and resource utilization during the 24-hour ED cycle.

Methods

Study Design and Data Collection

Data collected concurrently and in real time with individual ED patient encounters from July 1, 2004, through June 30, 2005, were included in retrospective analysis. The data points were captured automatically by the various hospital information systems as directed by the patient tracking system and stored in the ED Data Mart. Because the study analyzed data collected during routine ED operations and no protected health information was used, the study was exempt from institutional review and informed consent.

Setting

LDS Hospital is a 520-bed Level I trauma center affiliated with the University of Utah School of Medicine. It is a tertiary care center, serving as a referral trauma center for a three-state region, and is also a cardiovascular center with open-heart capabilities, a neurosurgical center, and a transplant center.

It is the flagship hospital for Intermountain Healthcare (formerly IHC), a system of hospitals, clinics, and health services serving 450,000 subscribers in the mountain west region. Although the hospital is now affiliated with an emergency medicine residency program, the program had not yet begun during the period of data collection for this study. Other residency training programs (surgery, transitional, and internal medicine), however, did send residents to rotate through the ED during the entirety of the study period.

Table 1. Characteristics of LDS Hospital Emergency Department (ED), June 30, 2005

Census:	39,667 ED visits
Pediatrics:	4%
Trauma Status:	Level I Trauma
Admission Rate:	23%
ICU Admission Rate:	25%
Overall Turnaround Time:	178 minutes
Discharged Turnaround Time:	160 minutes
Total Walkaways:	1.4%
Complaint ratios:	0.8/1000 ED visits
Radiology Utilization:	37%
Laboratory Utilization:	46%

* ICU, intensive care unit.

The ED is a 33-bed department with approximately 40,000 visits annually with the highest case mix index in the state. There is neither a fast track nor an observation unit. The ED's characteristics are summarized in Table 1 (above).

The ED uses bedside registration and charting with computer terminals in every room, digital radiography with real-time final radiology interpretations, bedside ultrasound, ED communication radios, advanced triage protocols, and point-of-care testing. These operational features were already in place when the new tracking system was being designed.

LDS Hospital and Intermountain Healthcare have a 30-year investment in information systems to facilitate health care. The HELP (Health Evaluation through Logical Processing) system is the integrated computerized hospital information system in clinical use at LDS Hospital that incorporates nurse charting, laboratory, registration, and the radiology system.*

* A new HELP2 system is a Web framework in development that will replace the old HELP system with a new suite of applications. It will take advantage of Intermountain Healthcare's core infrastructure, including the Clinical Data Repository, the Health Data Dictionary, and the Enterprise Master Person Index (EMPI).

Methods of Measurement

The Integrated Tracking System and Data Mart. The PTS is a Web-based status board analogous to the white grease board that is used to track patients' progress throughout their ED visit. The tracking system serves as a command central and communication board and provides information on the following data elements:

- Available beds staffing (physician, nurse, resident, student)
- Registration status
- Laboratory: Ordered/sent/cueing for results
- Radiology: Ordered/sent/cueing for results
- Orders: Cueing nurse for orders/completion
- Patient acuity
- Chief complaint
- Discharge cueing
- Consultations
- Waiting for room
- Housekeeping

Results entered from the registration, radiology, and laboratory systems cross over and cue the staff (without needing an extra data entry in the emergency department). The electrocardiogram, radiology, and laboratory technicians and nurse all indicate on the tracking board when their tasks are complete. This helps provide interval time data. Similarly, physicians are asked to indicate with a mouse click when they have seen a patient and to cue for orders and discharge. By integrating all other systems with the tracking system, much data entry happens automatically by crossover from one system to another. For instance, when the first laboratory test result is available, it crosses over to the tracking system and cues the staff that there are laboratory data available.

Before the PTS's development, the hospital had a comprehensive electronic health information system but no tracking system for the ED. In fact, until 2002, when the system went live, the ED still used a white grease board, although all the other data elements were computerized. A key feature in the development of this homegrown IT system was the integration of all operational systems critical to ED patient flow into the PTS and ED Data Mart. In short, all the electronic data elements relevant to the patient's ED visit were automatically and passively transferred into the tracking system and were stored in the ED Data Mart, the data repository.

Data Collection. Because the tracking system that feeds data into the Data Mart also serves as a status board that is used by all ED physicians and staff, spot audits have shown personnel to be highly compliant in entering data points into the system.

Outcome Measures

The outcome measures are now described.

Census by Hour of Day. The number of patients physically present in the ED by hour-of-day was counted. An hour was defined as the 60 minutes following the whole hour. For example, the hour of 12:00 P.M included 12:00 to 12:59 P.M. This definition was consistent through all parameters analyzed. Admitted and discharged patients were counted as present until they physically left the department and a nurse cleared them from the tracking system. Once a patient is physically present in the hospital, even briefly in the waiting or triage areas, he or she is tracked as an encounter.

Arrival by Hour of Day. The number of new patient arrivals—the absolute number of new patients who presented to the ED in a given specific hour—was tracked.

Average Acuity by Hour of Day. The ED uses a five-level triage scale, with the lower number signifying more emergent status. The triage algorithm used at our facility is comparable to the emergency severity index (ESI) in that it assigns a patient's triage score (1–5) based on the severity of illness and the anticipated number of resources (for example, lab tests, x-ray) that he or she will require during their stay.[13,14] A score of 1 was assigned to patients likely to require multiple resources, and a score of 5 to patients requiring relatively few resources. The average patient acuity was calculated for the patients present in the ED at any time during the given hour. This measure, one of the key operational metrics displayed on the PTS, is updated minute-by minute and stored in the Data Mart for later analysis.

Radiology Operations by Hour of Day. Orders for radiographic studies are entered into the electronic radiology system by the ED clerk. The clock then begins for radiology operations. Radiology data are categorized by modality (for example, computed tomography, conventional radiography, ultrasound) through drop down point-and-click boxes on the tracking system. Although we have stored data with even greater granularity (each time interval from radiology order entry through completed dictation of the report is tracked), thus far we have only analyzed radiology utilization data. The different modalities are grouped together and identified simply as radiology orders, and average hourly radiology order counts are presented. The radiologists use digital radiography with voice recognition transcription software to produce real-time radiology interpretations.

Laboratory Operations by Hour of Day. The time, number, and type of laboratory orders are also recorded by the EDIS, with progress indicated in real-time on the PTS. The system also records time to specimen collection and time to results. As with radiology orders, laboratory orders were counted, grouped by the hour of the day in which the order was generated, and then averaged for the year of study by the hour of the order. When the first results of any laboratory tests are available, the PTS provides a visual alert to that effect. When all laboratory test results are in, or when a predefined critical laboratory value is received, additional alerts are automatically displayed on the PTS. Although data on each of these time markers and results are recorded within the ED Data Mart, this study only reports general laboratory orders by time of day. By tracking each time interval of an ED operation, bottlenecks and delays may be identified and maximum efficiency achieved and maintained, as is done in other service industries.

Turnaround Time by Hour of Day. Mean turnaround times—the total elapsed time from when the patient is recognized as an ED encounter (initial presentation as an ED patient) until the time when the patient has physically left the department and is cleared from the PTS—were collected by hour of day and evaluated for trends, correlations, and statistical significance.

Admission Rate by Hour of Day. This rate—the number of patients admitted from the ED to any inpatient setting, divided by the number of patients seen by providers in the ED—was calculated by hour of day and averaged across the year of study. The time of admission was logged as the time when the patient physically left the department and was cleared from the tracking board, which eliminates time errors introduced when patients are boarded in the ED while waiting for beds.

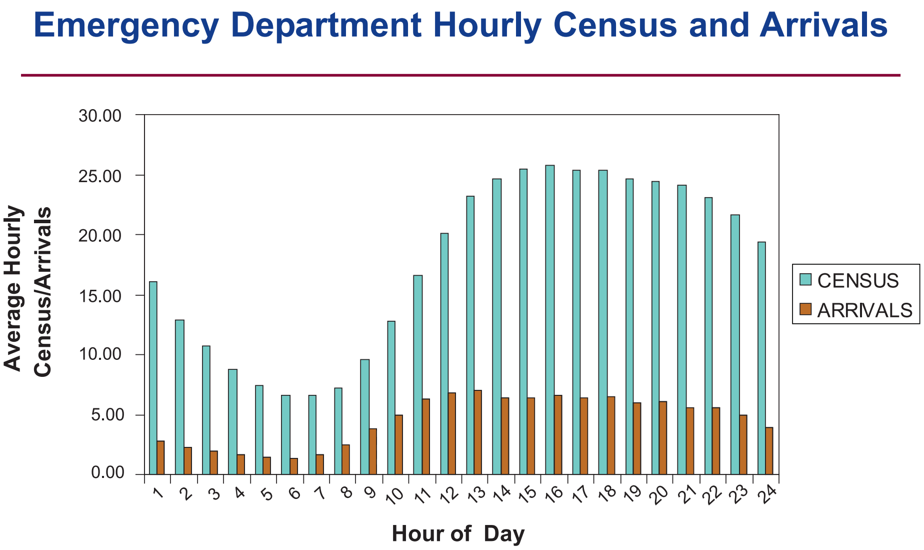

Figure 1. *The emergency department census curve mirrors the arrival curve but lags slightly behind it, reaching its peak at 3:00 P.M. and remains elevated until midnight*

Results

Data were analyzed for 39,704 ED encounters from July 1, 2004, to June 30, 2005, yielding some informative daily patterns.

Arrivals and Census by Hour of Day

Like most departments, arrival to this ED by hour is not constant. The arrival rate increases sharply in the late morning, peaks at midday, and remains high until 10 P.M. (Figure 1 (above). Chi-square tests for equal proportions showed that there were statistically significant ($p < .01$) differences for both hourly arrival rate and hourly census.

Average Acuity by Hour of Day

One-way analysis of variance (ANOVA) showed differences between the average acuity for the three ED shifts to be significantly different (Table 2, page 251). Figure 2 (page 251) shows acuity to be highest between 1:00 A.M. and 5:00 A.M., and lowest (with the highest ESI scores indicating lower acuity) between 7:00 A.M. and 1 P.M.

Table 2. Triage Acuity by Shift*

Shift	Number (*n*)	Mean Triage Acuity (ESI)	S.D.
Day (7:00 A.M.–3:00 P.M.)	15,712	3.21	0.744965682
Evening (3:00 P.M.–11:00 P.M.)	16,941	3.18	0.697819511
Night (11:00 P.M.–7:00 A.M.)	5,844	3.12	0.647773707

* ESI, Emergency Severity Index; S.D., standard deviation; 1,207 patients had no triage acuity recorded for analysis. A lower ESI number signifies higher acuity.

There is another period of lower acuity on the evening shift. There was a statistically significant correlation (r = .48, p = .02) between acuity and ED census. This relationship is evident in Figures 1 and 2; the graphs appear to be nearly the inverse of each other—mirror images. Put another way, patients seen during low-census times, in the middle of the night, appear to have a higher acuity.

Radiology and Laboratory Operations by Hour of Day

Pearson correlations showed that radiology utilization is highly correlated with ED arrivals (r = .96, p < .01) and patient census (r = .97, p < .01). As the afternoon surge of patients arrives, so does the need for radiology services (Figure 3, page 252). In fact, more radiology studies are ordered between 12:00 P.M. and 8:00 P.M. during the other 16 hours of the day combined. As with radiology, laboratory utilization is significantly correlated with ED arrivals (r = .94, p < .01) and census (r = .94, p <.01), and the average number of laboratory tests ordered between 12:00 P.M. and 8:00 P.M. is also higher than the number of tests ordered during the other 16 hours of the day. However, when the number of laboratory test orders and radiology orders per patient were calculated (Table 3, page 252), a multivariate analysis of variance (MANOVA) showed that there were statistically significant differences (p < .01) between the laboratory and radiology utilization by acuity—the higher the acuity, the more laboratory and radiology utilization.

Turnaround Time by Hour of Day

The mean turnaround time in the ED for all patients (whether admitted or discharged) was 174 minutes. The turnaround time for an ED patient was the longest during the time interval between 4:00 A.M. to 7:00 A.M., remaining increased above the average (at 180 minutes) through 11:00 A.M., hovering around the mean from noon through the afternoon, and then beginning to decline after 6 P.M. (Figure 4, page 253). There was a statistically significant inverse correlation between turnaround time and census (r = –.60 p = .02). Put another way, the higher the census the faster the turnaround time. On the other hand, the relationship between turnaround time and rate of arrival, while also inverse, did not reach statistical significance (r= –.35, p = .09). Individual patient turnaround time was correlated with acuity (r = –.30, p < .01); the higher the acuity the longer the turnaround time. Further,

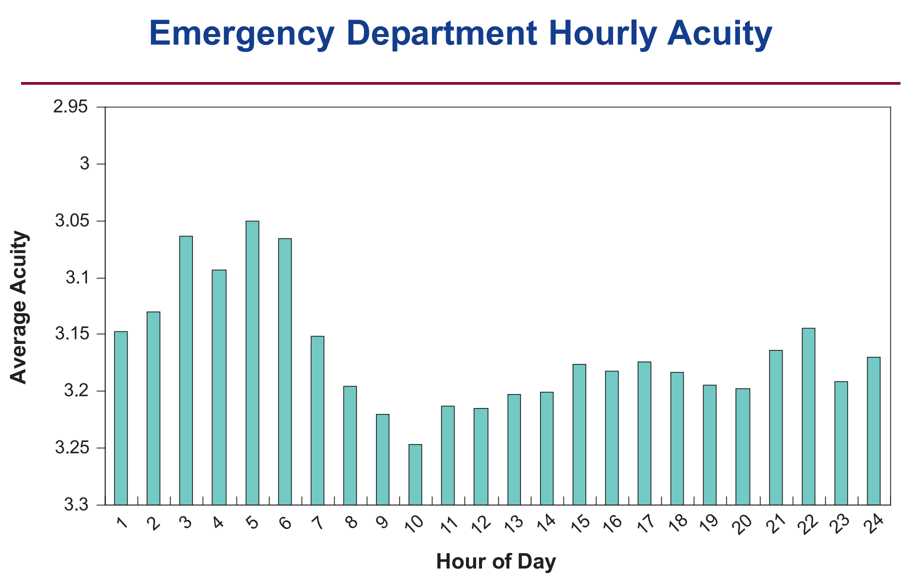

Figure 2. *Visual analysis of the figure shows acuity to be highest (with the lowest Emergency Severity Index scores indicating higher acuity) between 1:00 A.M. and 5:00 A.M., and lowest between 7:00 A.M. and 1:00 P.M.*

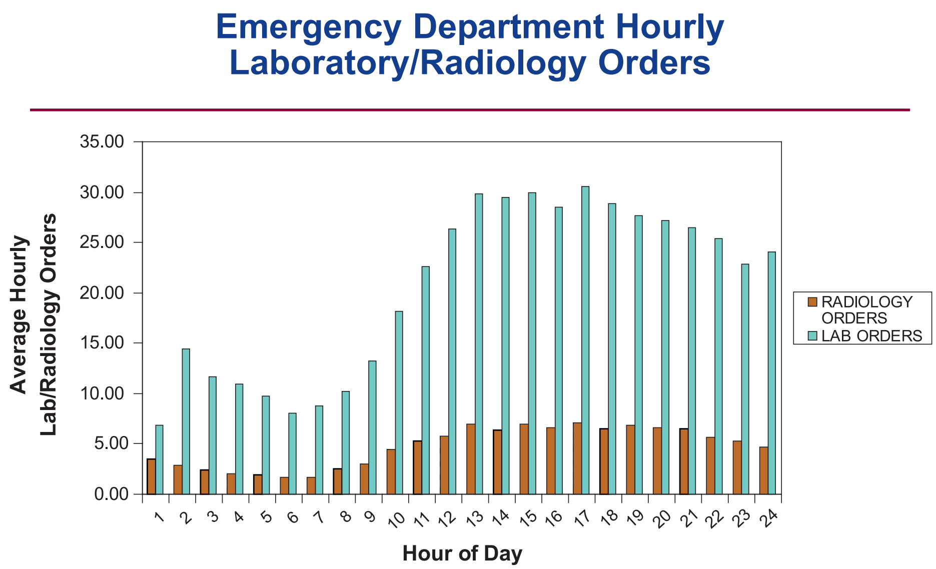

Figure 3. *Both the laboratory and the radiology utilization curve show clear correlation with arrival and census.*

individual turnaround time correlated with radiology utilization (r = .42, p < .01) and laboratory utilization (r = .31, p < .01); the more a patient utilized diagnostic modalities in the ED, the longer the ED turnaround time. This is becoming a recognized trend: as patients present with increasingly complex medical problems, they utilize more diagnostic resources and spend more time in the department.

Admission Rate by Hour of Day

The average admission rate during the period of analysis was 19.4%, a rate that varied less by hour than the other metrics mentioned above. It was significantly correlated with the average hourly acuity (r = –.55, p <.01). This relationship is supported by the fact that admission rates are elevated in the early morning hours when the average patient acuity is higher (Figure 5, page 254).

Limitations

Some of the data captured in the ED Data Mart required manual data entry at some point, and the exact accuracy of these points may therefore be suspect. However, because these data were drawn from points entered into the PTS, which serves as a communication center as well as patient management system and status board, most of the staff entering the data would have been affected by the accuracy of the entered data. For instance, if a nurse discharged a patient from the PTS before the patient had physically departed the ED, housekeeping staff or a new ED patient would collide in that room. Most data entry served patient care, occurred in real time, and was part of our routine operations. This functional aspect to the data makes it inherently more reliable, although not without errors introduced by human error associated with manual entry.

In addition, it is possible that staff may have been motivated to “game the system” and enter “dirty data” for data points requiring manual entry. For example, on average, our patients spend 11 minutes from initial contact with a registration clerk until they are placed in a treatment room. A physician might indicate that he or she had “seen” a patient on the PTS minutes before actually evaluating the patient, thereby producing a measurable decrease in the “door-to-doctor” time. In fact, our system monitoring processes have detected evidence of some of these types of behaviors. However, there are incentives against them because the data are used in real time and

Table 3. Laboratory and Radiology Utilization by Triage Activity*

Triage Acuity Level (ESI)	Number (n)	Mean Laboratory Count Per Patient	S.D.	Average Radiology Count Per Patient	S.D.
1	427	13.5	13.9	4.7	4.9
2	3,995	9.2	7.5	2.0	2.7
3	23,762	5.2	5.1	1.1	1.3
4	8,739	1.2	2.8	0.5	0.9
5	1,574	0.5	1.6	0.2	0.6

* ESI, Emergency Severity Index; S.D., standard deviation; 1,207 patients had missing values for acuity. A lower ESI number signifies higher acuity.

cue the commencement of advanced triage protocols. In this study, much of the data presented were acquired automatically by the various electronic systems and were therefore free of human bias or manipulation.

Finally, the data came from a single institution. Although the sheer number of the data points would tend to produce a true average that should extrapolate to other hospitals and settings, our environment may indeed be unique. The resultant data patterns may also be unique to our type of hospital—a community, tertiary care and trauma center. However, it is more realistic to anticipate that these data patterns would at least be consistent with similarly collected data sets at cohort hospitals (acute, urban, high-CMI hospitals), if not all EDs.

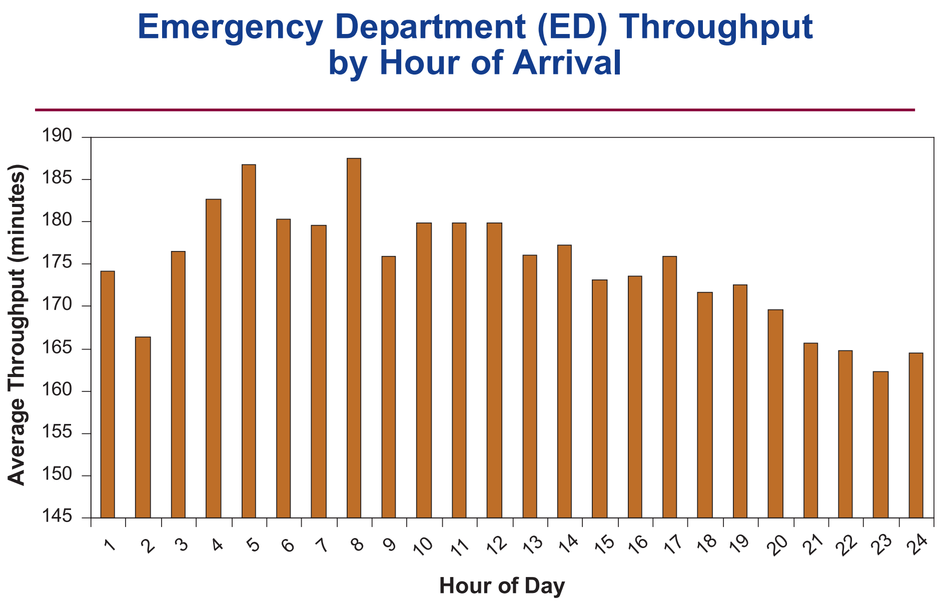

Figure 4. *The turnaround time for an ED patient was the longest during the time interval between 4:00 A.M. to 7:00 A.M., only beginning to decline after 6 P.M.*

Discussion

Many emergency physicians have reported that information systems such as those described in this article offer opportunities for improvement in ED operations and patient flow.[15–18] Any emergency practitioner can attest to the observation that the ED milieu cycles and changes throughout the day. This article may represent the first reported effort to use information technology to quantify this observation and show how the identified patterns can be used to anticipate the resources needed and the services required for efficient patient flow.

The data indicate that from late morning until mid-evening, the influx of patients into the ED is almost three times the rate seen in the early morning hours. This arrival by time curve has been recognized across hospital cohort groups.[19] From late morning most departments will struggle to keep pace with arrivals of less acute patients. This predictable patient influx will result in a surge of radiographic and laboratory resource utilization. According to our data, the increase in utilization of these services has a nearly 1:1 correlation with the increase in arrivals by hour of day curve. Yet most hospitals do not triple their staffing for the late afternoon and early evening.[20] In fact, the scheduling of most service departments falls off after 5:00 P.M., just when (according to our findings) the ED is most in need of those very services. This observation illustrates a fundamental mismatch between service availability and service needs, which has been noted before, that will ultimately require reconciliation. Indeed, the sobering finding that survival from acute myocardial infarction is a function of the day of week and the time of day has opened the door to such discussions.[21] We have mapped out the relationship between acuity and resource consumption, which has been noted before,[22] with more granularity.

The influx from late morning on also supports the implementation of the fast track in many departments of moderate to high volume. In general, it will take a department until nearly midnight to recover from the evening patient surge and its stress on the department and ancillary services. While the staff is typically catching up with documentation and stocking, the arrival of higher acuity patients who utilize more resources begins. Even after 9 P.M., as the rate of new arrivals falls, the department is still quite full in an effort to "clean up" as

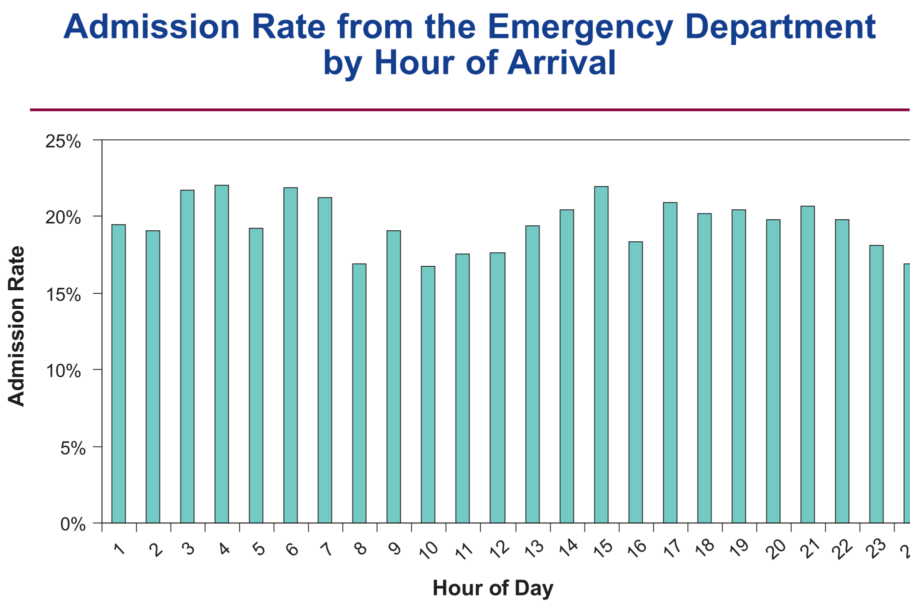

Figure 5. *The average admission rate was significantly correlated with the average hourly acuity (*r = –.55, p <.01*).*

it were, after the surge capacity arrivals. This lag in census adjustment may indicate that patients in the ED during low-census times will predictably stay in the department longer, both as a function of their higher acuity and as a function of resource availability and shift behaviors, as pointed out.

This observation is likely consistent with the clinical experience most practitioners have while working in the trenches. The evening stress is volume; the night stress is acuity and the holding of "social problems."

Are these variations in volumes, acuity, and resource utilization a function of the patients themselves, or are there any "shift behaviors" that influence flow? For example, we frequently hold inebriated or drug-impaired patients in observation status overnight, a practice common among urban centers. Further, many homeless patients board in the ED at night because the shelters are closed (a situation not encountered during the day). There is often nowhere for such patients to go and no way for them to get there. This is an example of the ED's safety net function in the community.[23] Finally, despite the ED being open 24 hours a day, 7 days a week, not all services are available at night. Consequently, the phenomenon of "holding over" patients until morning for cardiac stress testing, consultations, ultrasound or other diagnostics, is prevalent in many EDs. Again, the fact that different resources are available at different times of the day may lead front-line practitioners to devise different plans for their patients on the basis of the hour of the day. This further supports our observation of a 24-hour ED cycle with different volumes, acuities, and resource utilization.

Are there other "shift behaviors" working in the other direction? Perhaps on the busier portion of the ED cycle, physicians and staff become comfortable with a "deferred diagnosis" approach. When a department is in a state of overcapacity, physicians may ask the patient who is stable to return the following day for further diagnostics. The study of shift behaviors relative to the ED census will likely prove an intriguing one for further research.

Mapping the 24-hour ED cycle quantifies the ED experience and helps us to define what it is exactly that we do. It will aid us in better caring for all of our patients by better predicting department needs, and is long overdue. In addition, such data will aid us in demand capacity management as we borrow the science and tools used in this area by other service industries.

EDs have been charged by the Joint Commission,[24]* the Centers for Medicare & Medicaid Services (CMS),[25] and even the public at large to address their flow problems. Although some of the factors in ED overcrowding and patient flow are beyond our immediate control, it is time to recognize how information technology can help with this task. Although most quality service managers have focused their efforts in clinical areas, these data illustrate the likely impact of operational efficiency on quality of care. J

* Standard LD.3.15: The leaders develop and implement plans to identify and mitigate impediments to effective patient flow throughout the hospital (LD-11).

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