SIGNA VITAE 2016; 12(1): 52-57

# Improving Emergency Department Capacity Efficiency

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## ABSTRACT

Objective. The demand for emergency services has risen dramatically around the world. Many Emergency Departments (EDs) have signs of low capacity efficiency (which we define as the rate at which a production facility with limited resources can convert input into output); insufficient resources (staffing, equipment, facilities), inefficient ways to use them, or both. Our purpose was to investigate how to improve ED capacity efficiency through layout planning and present some novel ideas of ED bottlenecks.

Methods. We adopted an industrial engineering perspective to one Finnish ED as a case example. In contrary to a simple case report we used more generalizable methods and demand-supply chain analysis to improve capacity efficiency.

Results. This study resulted in concrete and generalizable improvements of capacity efficiency concerning both ED premises and staffing. The former includes designing patient locations, organizing beds, improving space usage and optimizing an ED layout. The latter identified the demand for different specialties and optimal allocation of nursing staff.

Conclusion. We present a rather unique combination of ways to enhance ED functionality by using methods of industrial engineering.

*Key words: capacity efficiency, emergency department, operations management, healthcare*

## INTRODUCTION

A trend of increasing emergency service demand has been observed internationally. (1-3) At the same time Emergency Departments (ED) have increased their importance as a part of the access system through which patients enter inpatient clinics. (4)

A constant increase of demand and a continuous need of services create a corresponding need to increase and develop the supply of emergency services without giving any room for cost cuttings. (5,6) Since the new management principles of the 1980s and 90s, the development of healthcare process management has had direct and predictable efficiency effects. (7-9) Still, after a certain point, the facilities and other resources can't keep up with the pace, and as signs of low capacity efficiency appear, many EDs have either insufficient resources or inefficient ways to use them. (10,11)

A lot has already been investigated in terms of resource allocation, process standardization, patient classification and prioritization, queuing discipline, implementation of electronic systems and specific process improvements. (11-22) However, there seem to be no studies that have improved ED functions through operations management based layout planning.

Prior to this research, the case specific perspective of improvement in ED efficiency has had a seriously hampering effect on the generalizability of ED process re-engineering on an universal level, though Emergency Medicine (EM) itself can be seen as rather universal across health systems. (23)

In this research, we adopted an industrial engineering perspective to one Finnish ED as a case example of improving capacity efficiency through demand-supply chain analysis. We share the definition of capacity efficiency as the rate at which a production facility can convert input into output. (24,25) This definition measures efficiency with limited resources. We hope to present methods that can be more universally generalized than previously. Our purpose is to investigate how to improve ED functions through layout planning and present a few novel ideas of modern day ED bottlenecks (i.e. recumbent patient places, nursing staff and physicians belonging to different specialties).

## MATERIALS AND METHODS

During the field work of our study the county of Kanta-Häme was on the verge of organizational renewal of emergency services. The political decision to build a new

ED had already been made, a process originally starting four years before completion. In addition, another main goal of this renewal was to gather all emergency services into one place by integrating primary care emergency duties to the secondary care ED. This new ED was designed with capacity efficiency in mind. The fieldwork of this study lasted eight months, and its results were later utilized in the planning process of the new ED.

Quick analyses revealed that the old ED had several drawbacks in its capacity efficiency. First of all, it was designed in the late 1970's for predominantly ambulatory patients, counting on a total of only 12 000 annual visits. According to staff, there had been a major shift from ambulatory to recumbent patients over the years. The other observation concerned the long length of stay (LoS). Critical resources had to be either inadequate or inefficiently organized since a long wait and LoS prevailed.

There had been no earlier studies of capacity efficiency in this ED. To enhance capacity efficiency we decided to search improvement possibilities in layout design, beds, use of nursing staff and physicians belonging to different specialties. We were able to formulate the general research question as follows:

How should ED resources be reorganized in terms of premises and staffing in order to increase capacity efficiency?

Analytically, we approach capacity efficiency from two aspects, a) resource efficiency (through purely technical efficiency as well as utilization rate) and b) resource availability. Resource efficiency illustrates how well resources are used. In other words how much output is achieved from a given amount of input (i.e. resources). Another typical key figure for resource efficiency is the utilization rate. It tells how much of the potential capacity is used. Resource availability tells how much of the demand is allocated per one resource unit. It tends to have an optimal level rather than an aimed tendency towards a big or small value. Greater values are a sign of insufficient capacity and smaller values of excess capacity. However, the optimal levels and ways to figure them out are very case-specific. One may wish to use for instance simulation or linear optimization in order to determine optimal levels.

To increase capacity efficiency one needs to make corrective actions like reorganizing existing, enhancing the availability or adding or reducing resources.

Since mixed-method case studies are suitable to investigate complex real life events, (26) our semi-triangulative research approach contained the following three methods to gather the data. Firstly, the key ED employees were interviewed to get the overall picture of the functions and problems. In addition, based on these interviews the numeric data needs were identified. Secondly, hospital databases were searched for all possible patient details. Thirdly, a two-week patient follow-up was organized to acquire additive field information concerning ED processes.

Interviews, done on several different employees to guarantee consistency and reliability, encouraged studying some parts of the functions more carefully. The following numeric data needs were identified: daily demand for emergency services, patients' arrival times, lengths of stay, the number of patients that needed a bed during their stay, the number of different spaces used during an ED stay, the number of bed transportations, and the demand for different specialties.

The number of ED visits and patients' arrival times were revealed from hospital databases. The data were collected over three months, January, March and September with a total of 4463 observations.

A manual follow-up was carried out from Nov 24th to Dec 10th to gather the number of different spaces used during an ED stay. The number of bed transportations and the utilization of different specialties were documented by our nursing staff for 491 patients, which correspond to 80% (491/614) of all ED admissions during the period. All new data were confirmed for consistency prior to adding them to the database.

### Statistical Methods

All the data were filed in Microsoft Office Excel. A daily cumulative distribution chart of patient visits was calculated as well as distribution charts of hourly patient arrivals and hourly LoSs. The daily average number of recumbent patients was calculated as a percentage of the total daily visits.

For space usage and demand for consultative support by specialty services, a percentage of patients in corresponding areas or specialties were divided by the total amount of patients. This method was applied to each meaningful separate space in the ED as well as to each specialty.

The need for beds was calculated within MATLAB® 6.5 environment. Two vectors were created, one for average hourly LoS distribution and the other for hourly patient arrival time distribution. These two vectors were then convoluted and finally multiplied with the estimated amount of daily patients and the percentage of recumbent patients. Since daily bed needs overlap because of long LoSs and around-the-clock arrival times, the calculations were run for consecutive three days to see the accumulation of patients bed needs. Following the previous steps one can adjust the desired bed coverage level by choosing the desired daily patient amount from a cumulative distribution function of daily patient volumes. In our case, to make it even simpler and to present the bed demand, the maximal need for beds was finally plotted against different levels of patient volumes.

## RESULTS

At the time our case hospital, Kanta-Häme Central Hospital, had 18 000 annual emergency visits providing secondary care for 166 000 people. The ED area was 940 m2 and had 12 primary beds for recumbent patients. In addition there were two observation rooms: six places for men and six for women. There were also two waiting lobbies for ambulatory patients. Recurrent overcrowding was handled by placing extra beds wherever they fit.
Two physicians in training, an internist and a surgeon, handled the emergency duties. Although consultative support was available to the physicians, it varied by specialty and was given either by phone or by visit. Each shift was staffed with one porter and four to five registered and practical nurses.

## DESIGNING ED PREMISES

*1. Designing the patient places according to patient types*
Analysis revealed that the recumbent pa-

tients (76.4%, 375/491) were the dominating patient group and the primary beds were calculated to cover only 65% of the cumulative daily demand. Meanwhile the observation rooms were seen to be too far from the functional heart of the ED.

To avoid the noticeable risk of bed shortages the utilization rate was to be lowered to or below 85% as supported earlier. (4) Against this background we calculated that the supply of 15 primary beds would avoid the serious shortage problems 85% of the time, and the addition of only 2 beds to the total number of 17 primary beds would help to meet the demand at all times without special arrangements (figure 1). By increasing the number of beds to the proper level, the ED would benefit from increased customer and employee satisfactions with the improvement of the supply of services.

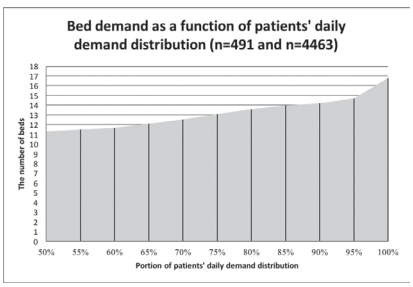


*Figure 1. Bed demand as a function of patients' daily demand distribution. Calculations are based on current demand.*

*2. Organizing the beds*

Our analysis revealed that all beds should be gathered into one shared patient area, enhancing direct visual surveillance and reducing transportation needs. Patients could be provided with intimacy through removable curtains or walls. Few places in the front of the patient area should be more heavily equipped for the patients in need of more intensive care, a design concept similar to business class in aviation.

As a further improvement, primary beds could be located in two areas, one for medical and the other for surgical patients. These transformations would increase the ED capacity efficiency in respect to resource efficiency by simplifying the processes and quality of care through decreasing need for patient transportations.

*3. Improving space usage*

Analysis of space usage revealed that 14 out of 19 different spaces were used at most by 15% (75/491) of the ED patients (figure 2). Thus, the utilization rates were mostly remarkably low. The least used places indicated low capacity efficiency, but due to special functions and inevitable existence the utilization rates of some of them (like isolation room and shower) did not present low capacity efficiency.

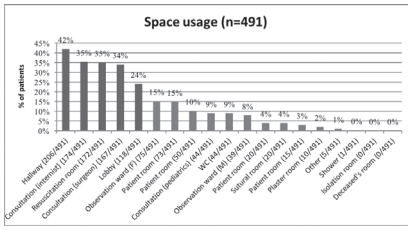


*Figure 2. Percentage of emergency departments (ED) patients that used different spaces (frequencies in parenthesis).*

The results spoke for the idea of multipurpose facilities, when it was clinically possible to use the same facilities for different functions. For example a shared consultation room for several specialties giving consultative support to the emergency physicians.

Combining procedure rooms (suturing and plaster rooms) was not clinically possible in this case, but it might be relevant in bigger EDs where the variety of different procedure rooms is greater. Altogether, these enhancements would increase utilization rates and save space for other uses, i.e. they would increase resource efficiency and thus capacity efficiency. Resource savings in space could be utilized by for example bringing more functions needed by the ED patients to the emergency facilities.

4. Making the ED layout more efficient

The main problem lied in impractically designed facilities, causing numerous long transportations and poor visual surveillance. Difficulties in visibility were a safety risk because of possible worsening of patients' conditions, increased violence and unrest among patients.

As a solution, we designed a layout sketch highlighting the most important connections between different ED functions (figure 3). The priorities were mapped through interviews and data analysis. The presented sketch is not a floor plan, but an idea of how different connections could be realized. All beds are centered and divided into areas for medical and surgical patients. Opposite to the two patient areas are the corresponding consultation rooms, reducing transportations to consultations and back.

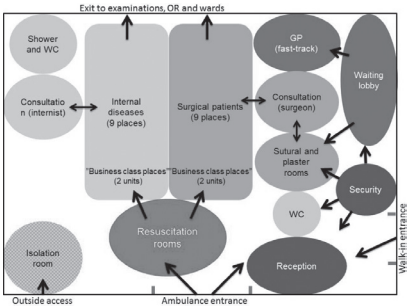


*Figure 3. Emergency departments (ED) layout sketch.*

Both consultation rooms provide a connection to resuscitation and the surgeon has his suturing and plaster rooms close by. Visibility and situation awareness are greatly improved because everything can now be seen from the ED heart. As a new feature, the security personnel are brought inside the ED to ensure its safety. This arrangement guarantees employees better mobility and improves capacity efficiency through resource efficiency by simplifying processes easing staff's work and yielding time savings.

## DESIGNING ED STAFFING

*1. Identifying the demand for different specialties*

As said, the ED had two physicians in training, i.e. an internist and a surgeon, on duty and available at all times treating all patients. In addition to his own specialty, the internist took care of neurological, pulmonary, psychiatric, physiatry as well as dermatologic and allergic problems. Correspondingly, the surgeon also treated gynecological, laryngological, and ophthalmological cases in addition to general surgical patients. Different specialists from other parts of the hospital, whose availability varied greatly, gave their consultative support to the duty officers.

The analysis showed that the primary duty officers were almost equally loaded, the internist in training having only slightly more patients (55.2% of total, 271/491), indicating no need for a rearrangement of specialty division.

After internal medicine and surgery, the most common problems were among the specialties of pediatrics and neurology, 9.6% (47/491) and 8.6% (42/491) respectively. These specialties constituted almost 30% (73/272) of all specialist consultations needed (figure 4).

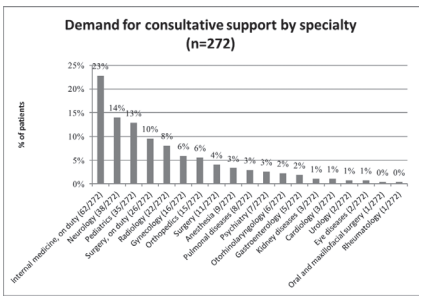


*Figure 4. Demand for consultative support by specialty (frequencies in parenthesis).*

The absolute number of consultation contacts was remarkably high because half of all cases required consultative support of a specialist during their treatment process. To avoid prolonged lengths of stays of pediatric and neurological patients, the hospital was obliged to improve the availability of these specialties in terms of consultative ED support.

In general, ED functions cannot be expected to be improved without interfering any interest groups' procedures. Capacity efficiency could be improved through enhancing the resource availability of external resources. Better supply of services was planned to reduce patients' lead-times and eventually length of stay, improving customer satisfaction and causing cost savings.

*2. Nurse staffing in accordance to patient demand*

The daily work of nurses in the ED was arranged in three equally staffed shifts. The only exception was the night shift, which had one nurse less than the others.

Our analysis revealed distinct trends in the patients' arrival distribution, implying a need for reallocating nursing staff (figure 5). A few employees should be assigned from night to day shift. To back up this solution, the ED could set few nurses into standby mode for the night.

Changes in the staffing structure were planned to increase the utilization rate since fewer nurses would handle the same number of patients. This way the resource efficiency and, in wider terms, the capacity efficiency could be enhanced. It can be assumed that a greater number of nurses during the day shift would reduce patients' lead-times. Of course the presence of other bottlenecks (e.g. physician, X-ray) might reduce the impact. Another aspect was that transferring work away from the night would yield in cost savings.

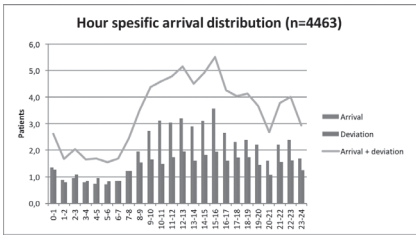


*Figure 5. Hour specific arrival distribution.*

## DISCUSSION

In this study we revealed improvements of ED functions through two perspectives of capacity efficiency: resource efficiency and resource availability. Demand-supply analysis was used as a method to analyze current capacity efficiency and to find improvement ideas. We revealed several concrete enhancements in respect to premises and staffing, which a local hospital administration can implement without legislative changes (table 1).

*Table 1. Enhancements to improve capacity efficiency.*

| Improvement | Impact | Degree of change |
|---|---|---|
| Definition of the adequate bed capacity, along with correct patient types | Increase in resource availability | Moderate |
| Establishment of a shared patient area for recumberrant patients | Increase in resource efficiency by process simplifications | Significant |
| Establishment of multipurpose facilities, combine fairly unused places | Increase in utilization rates and thus in resource efficiency | Moderate |
| Design of ER layout to better meet the process requirements, bring functionally related spaces close to each other | Improved resource efficiency through simplified processes | Significant |
| Enhancement in the availability of specialties' consultative support | Improvements in resource availability | Moderate |
| Reallocation of nursing staff into shifts in accordance with hour specific patient demand | Improvements in resource efficiency through higher utilization rates | Moderate |

Our perspective of analyzing the layout design of the ED has been rather undiscovered in the literature. Previous publications have focused on the layout of cubicles or rooms (27,28) and the effect of different processes and Lean methods on ED design. (29) This study brings a new extension to the research area of ED functions as our results concerning layout design are comprehensive and easily generalizable.

We brought up vital observations of patient characteristics in our case ED which can be utilized in the design of premises. Improvement suggestions handle the amount and placement of beds, mutual closeness and connections of the most important rooms, and the establishment of multipurpose rooms. Besides increasing capacity efficiency, these measures also simplify ED processes. The other areas of

our research i.e. nursing staff, physicians belonging to different specialties and bed capacity are familiar from the earlier ED studies. Although bed needs have been studied earlier, (20) no exactly similar approaches exist. Therefore the comparison possibilities with our study are rather limited, except for the bed dynamics results by Bagust et al., (4) used as a reference point in our calculations.

The solutions introduced in this study are tailored to our case ED. The suitability to different EDs depends heavily on such features as size, population area, resources, procedures, processes, roles of primary and secondary health care, and improvement possibilities. Let's take the example of multipurpose rooms. In a small ED, they are very functional and efficient in terms of utilization rates, but when the volumes grow the availability of single purpose rooms becomes again reasonable. (27) The individuality is also true with the improvement possibilities. Not all EDs are as lucky as our case entity to start designing their facilities from scratch. All suggestions of this study are therefore not at everyone's reach. For this reason the suggestions in table 1 are marked either "significant" or "moderate" to illustrate the degree of change.

A logical follow-up to this study would be the classification of different ED improvement solutions, especially in terms of the layout design. In addition to the catchment population of hospital, such factors as demographic statistics, roles of primary health care and hospitals as well as hospital type (secondary or tertiary care) are the basic determinants when studying the function of the ED. To find optimal structure of the ED, the research should be expanded to include also other aspects of premises, staffing and processes than already studied. For example, the recent evolution of the specialty of Emergency Medicine in many European countries has important effects on physician staffing, the need for consultative support (table 1) and process overlapping in the ED. (30,31) Constructing a framework of optimal ED structures for different circumstances requires multicase analysis through various ED settings.

Based on the framework suggested, a further question is raised: How can a structure be qualified as capacity efficient? Of course optimal levels could be defined for different measures, but first of all the most important thing is how the efficient use of capacity is shown in practice. We believe that striving for and attaining increases in capacity efficiency have variable but significant implications for hospital management by yielding a wide range of benefits related to direct and indirect cost savings, level of service, quality, safety and job satisfaction.

Further investigations into the dynamics between the types of concrete benefits, capacity efficiency and ways of increasing capacity efficiency are still needed. Obviously, finding generic links between certain re-engineering efforts, increases in capacity efficiency, and operating results would be immensely valuable. This, too, calls for multi-case analysis across ED types using identical re-engineering efforts.

In conclusion, our paper represents rather unique combination of ways to enhance ED functionality. The ease of implementation of these suggestions depends heavily on the underlying local situation, yet they should be considered now or latest before the next ED renovation.

## REFERENCES


1. Mason S, Mountain G, Turner J, Arain M, Revue E, Weber EJ. Innovations to reduce demand and crowding in emergency care; a review study. Scand J Trauma Resusc Emerg Med 2014;22:55.
2. Hsia RY, Nath JB, Baker LC. California emergency department visit rates for medical conditions increased while visit rates for injuries fell, 2005-11. Health Aff 2015;34:621-6.
3. Stakes. The number of secondary care emergency visits in Finland 1994-2001. SOTKA database. 2004.
4. Bagust A, Place M, Posnett JW. Dynamics of bed use in accommodating emergency admissions: stochastic simulation model. BMJ 1999;319:155-8.
5. Vries de G, Bertrand JWM, Vissers JMH. Design requirements for health care production control systems. Prod Plan Control 1999;10:559-69.
6. Karvonen S, Rämö J, Leijala M, Holmström J. Productivity improvement in heart surgery–a case study on care process development. Prod Plan Control 2004;15:238-46.
7. Berwick DM. Continuous Improvement as an Ideal in Health Care. N Engl J Med 1989;320:53-6.
8. Rotondi AJ, Brindis C, Cantees KK, DeRiso BM, Ilkin HM, Palmer JS, et al. Benchmarking the perioperative process. I. Patient routing systems: a method for continual improvement of patient flow and resource utilization. J Clin Anesth 1997;9:159-69.
9. Vissers JMH, Bertrand JWM, De Vries G. A framework for production control in health care organizations. Prod Plan Control 2001;12:591-604.
10. Fernandes CMB, Christenson JM. Use of continuous quality improvement to facilitate patient flow through the triage and Fast-Track areas of an emergency department. J Emerg Med 1995;13:847-55.
11. Jelinek G, Mountain D, O'Brien D, Rogers IR, Wilkes G, Wenban J, et al. Re-engineering an Australian emergency department: Can we measure success? J Qual Clin Pract 1999;19:133-8.
12. Pallin A, Kittell RP. Mercy Hospital: simulation techniques for ER processes. Ind Eng 1992;24:35-7.
13. Badri MA, Hollingsworth J. A Simulation Model for Scheduling in the Emergency Room. Int J Oper Prod Manage 1993;13:13-24.
14. Blake JT, Carter MW. An analysis of emergency room wait time issues via computer simulation. INFOR 1996;34:263.
15. Fernandes CMB, Price A, Christenson JM. Does reduced length of stay decrease the number of emergency department patients who leave without seeing a physician? J Emerg Med 1997;15:397-9.
16. González CJ, González M, Ríos NM. Improving the quality of service in an emergency room using simulation-animation and total

quality management. Comput Ind Eng 1997;33:97-100.
17. Hollingsworth B, Dawson PJ, Maniadakis N. Efficiency measurement of health care: a review of non-parametric methods and applications. Health Care Manag Sci 1999;2:161-72.
18. Kyriacou DN, Ricketts V, Dyne PL, McCollough MD, Talan DA. A 5-year time study analysis of emergency department patient care efficiency. Ann Emerg Med 1999;34:326-35.
19. Spaite DW, Bartholomeaux F, Guisto J, Lindberg E, Hull B, Eyherabide A, et al. Rapid process redesign in a university-based emergency department: decreasing waiting time intervals and improving patient satisfaction. Ann Emerg Med 2002;39:168-77.
20. Zilm F. Estimating emergency service treatment bed needs. J Ambul Care Manage 2004;27:215-23.
21. Martin M, Champion R, Kinsman L, Masman K. Mapping patient flow in a regional Australian emergency department: A model driven approach. Int Emerg Nurs 2011;19:75-85.
22. Madsen M, Kiuru S, Castren M, Kurland L. The level of evidence for emergency department performance indicators: systematic review. Eur J Emerg Med 2015; 22:298–305.
23. Eisenhardt KM. Building theories from case-study research. Acad Manage Rev 1989;14:532-50.
24. Hoover WE, Eloranta E, Holmström J, Huttunen K. Managing the Demand-Supply Chain: Value Innovations for Customer Satisfaction: Wiley Operations Management, 2001.
25. Plambeck EL, Taylor TA. On the value of input efficiency, capacity efficiency, and the flexibility to rebalance them. Manuf Serv Oper Manag 2013;15:630-9.
26. Yin RK. Case Study Research: Design and Methods: SAGE Publications, 2013.
27. Saba JL, Bardwell PL. Universal design concepts in the emergency department. J Ambul Care Manage 2004;27:224-36.
28. Zilm F. A new era of emergency care: planning and design consideration. J Ambul Care Manage 2007;30:259-63.
29. Zilm F, Crane J, Roche KT. New directions in emergency service operations and planning. J Ambul Care Manage 2010;33:296-306.
30. Naskali J, Palomäki A, Harjola V-P, Hällberg V, Innamaa T, Rautava V-P. Emergency Medicine in Finland: First Year Experiences of Specialist Training. JAEM 2014;13:26-9.
31. Graham CA. Coming together to advance the specialty of emergency medicine in Europe. Eur J Emerg Med 2014;21:393.