Optimizing The Emergency Department: The Case of Mount Lebanon Hospital

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Abstract— **Emergency departments (ED) are a primary interface between patients and the healthcare industry. In this study, we focus on optimizing the ED of Mount Lebanon Hospital. This specific hospital unit is known to be a very dynamic place, where a considerable amount of processes and decision-making takes place. A lot of issues and obstacles may arise and interfere with the efficiency and accuracy of the services. Therefore, optimizing the overall management of ED's is of an extreme importance. In this work, we focus on generating industrial engineering solutions in MLH's ED and implementing them in their new expanded unit. In order to do that, we allocated a considerable amount of time in researching and observing the ED's procedures. Our goal was to be able to optimize the quality of the services while providing industrial engineering solutions accordingly for the future unit. In the remaining work we will perform simulation with ARENA software to decrease patients' waiting time and waste. Also, we will be working on optimizing the ED's layout to increase efficiency and productivity. Lastly, we will be tackling the matter from an ergonomic perspective.**

Keywords—emergency department, noise level, waiting time

I. Introduction & *Motivation*

The ED plays a prominent role in hospitals not only because of its frequent interactions with all of the other departments but also because of the direct impact it has on patients' lives. Moreover, 50 to 75% of the patients who are admitted in hospitals go through ED's [1]. Therefore, the quality of service and care in ED's highly affect the patient's journey, highlighting the importance of optimizing the processes and pursuing continuous improvements.

Founded in 1995, MLH is one of the biggest hospitals in Lebanon that accommodates a total of 450 beds. Currently, the hospital is expanding its ED. The current one suffers from increased length of stay of patients, poor management of shifts between personnel and conformation to standards and guidelines by the medical staff. It has been shown that ED overcrowding is highly correlated to increased patients length of stay, longer waiting time, and 20 to 30 % of mortality rates [1]. Using an industrial engineering approach, we decided to take on the project of optimizing the current ED in order to implement improved and optimal processes in the new department. The idea of contributing to the improvement of the healthcare sector in Lebanon has driven us to pursue this project. Providing the highest quality of care, enhancing the patient's overall experience and boosting the hospital's reputation are a must to achieve our ultimate goal of having a positive impact in improving people's lives.

II. Goals and Objectives

Our first objective consists of maximizing the quality of the services in MLH's ED. The first aim to reach this objective is through conducting surveys and interviews with people involved, as well as constructing a Supplier-Input-Processes-Output-Customers (SIPOC) diagram. As for the second aim, it involves establishing Critical-To-Quality (CTQ) characteristics, Key Process Input Process (KPIV) and Key Process Output Process (KPOV), and then analyzing their current state through root cause analysis. Last but not least, we focus on determining criteria and regulators that help maintain the proposed improved solutions in the long term. Moreover, our second objective targets the efficiency of the processes in the ED. It consists in first simulating the arrival, waiting and service times of patients, and second in proposing a new facility layout. Finally, the last objective addresses the safety and wellbeing of the patients and medical personnel in the ED. For that, it is necessary to forecast the demand in the ED in order to develop a suitable and flexible schedule for the nurses, physicians and doctors in charge; and manage the inventory and stocks. Also, ergonomics is an important tool that helps in developing alternatives that improve the interaction between nurses and patients.

III. Background

ED management is an international matter that can become hectic especially in times of crisis. In fact, mismanagement can lead to unwanted situations for both the patients and the hospital such as overcapacity and extended waiting times, inadequate division of resources, waste and alteration of personnel's concentration. Another important issue to point out is the satisfaction of not only the patients but also the nurses, as one in four nurses are not content according to a study done in Canada [2]. Subsequently, optimizing ED plays a major role in helping the hospital to be more adept in times of crisis.

A. Causes of a Non-Optimal ED

To start with, patient flow is an important cause of ED crowding. In fact, right after their arrival to the ED, patients undergo a triage where they are categorized into five classes depending on the urgency of their cases. Patients with non-urgent cases are the ones who actually require primary care but go to EDs instead due to accessibility. This being said, primary care is more appropriate for 29% out of 500 frequent patients who visit the ED at least four times yearly. Those represent 8% of the total annual visits [3]. Additionally, the capacity of the hospital's ED plays a crucial role in overcrowding. In the case of MLH, the ED includes a total of 14 beds. A study showed that the number of beds is negatively associated with ambulance diversions in which situations ambulances would transport patients to other neighboring hospitals [4]. Also, not only does the number of staff affect the operations of the ED, but so does their compliance to well defined procedures. Moreover, the inadequate division of resources is a cause for overcrowding that can alter the nurses and physicians' productivity and ability to focus. Lastly, the floor layout can be prone to bottlenecks and can lead to decline in productivity in the case where a lot of backtracking is required and noisy areas are close to areas that need to be rather calm. A noise study conducted at Johns Hopkins Hospital operation rooms consisted of taking the sound levels for a continuous 24-hour period using a sound level meter. After analyzing the results, it was found that the sound level often exceeds 90 decibels [5], which is the maximum exposure permissible for an 8-hour day according to the Occupational Safety and Health Administration (OSHA).

B. *Effects of a Non-Optimal ED*

Consequently, bad management of EDs has many repercussions on patients' health and satisfaction, particularly: one patient elopement, a delay in treatment, the mortality rate, financial effects to the hospital, and loss of productivity of the staff. For instance, in some situations when the ED is already full, patients who have already waited a certain amount of time abandon and leave the ED without receiving treatment. A study showed that around half of those patients effectively needed urgent medical treatment [6]. Another consequence for mismanagement is the delay in treatment, which is more often than not related to a higher pain assessment in severe cases. Besides, in extreme situations the mortality rate can rise due to overcrowding, and this is expressed in the number of yearly deaths in EDs that can extend to 13 according to a study done in Canberra Hospital in Australia [7]. A bad management is also reflected in the financials of the hospital as a reduction of one hour in the total patients' waiting time in the ED, increased the revenue by as much as 37.9% [8]. Finally, when the ED is crowded, the noise level is increased and this affects the physicians and nurses' ability to focus over a long period of time [9], which undoubtedly means a decline in productivity.

C. *Solutions to a Non-Optimal ED*

Lastly, after establishing the root causes and why it is important to tackle hospitals' management, a substantial body of literature exists that addresses solutions. Indeed, some of these solutions are industrial engineering type of solutions. In fact, methods such as the 5S can be continuously implemented with the ultimate goal to reduce all types of waste and optimize productivity. Indeed, the execution of the 5S in MLH's ED could help in reallocating the supplies in a single appropriate location in order to decrease staff flow. Additionally, Value Stream Mapping (VSM) is another truly efficient method, which is also applied to diminish patient idle types. The implementation of these techniques along with others have demonstrated a significant increase in patient satisfaction scores, as well as a 7% increase in volume, without even expanding the space nor adding new resources [10].

Moreover, simulation is a very effective tool that is used to model the patients' waiting time in the ED. Its utmost goal is to reduce the patients' length of stay by optimizing staff scheduling accordingly. Therefore, the scheduling of physicians and nurses is crucial in improving the productivity of the ED, and increasing the staff's efficiency [2]. A discrete event simulation model was run 50 times in the ED of the Regional University Hospital in Turkey. It showed a 45% decrease in patients' average waiting time after the implementation of an improved nursing schedule [11].

Additionally, the arrangement of triage nurse schedules, as well as a stricter triage process, has a significant impact on the patients' waiting time. One solution would be to provide a fast track area for patients with non-life threatening cases i.e. in categories (3-4-5) in the case of MLH's ED, and a full time fast- track nurse. In fact, these nurses will be responsible for patients not needing intensive care. Figure 1 shows the patient's flow in the ED.

Applying these solutions in St. Paul Hospital's ED in Vancouver decreased the average patient's length of stay from 67±31 minutes to 57±34 minutes [12]. Similarly, other continuous quality improvement tools can be executed in order to better manage the ED crowding.

Nevertheless, managing the capacity related to bed capacity is key to reducing overcrowding and waiting time. MLH's ED currently accommodates a total of 14 beds. In peak times, the management is forced to ask non-urgent cases to leave their beds for life-saving patients. In fact, this interferes with the customers' satisfaction as well as the hospital's reputation. Therefore, having more beds in the ED would likely lead to a decrease in average waiting-time.

IV. METHODS

A. *Interviews and Surveys:*

In order to maximize the quality of the services, we started by observing and gathering the largest possible amount of information so as to get familiar with the processes. To better understand the system and the flow of patients, we developed a SIPOC diagram. In fact, it shows the main suppliers, inputs, processes, outputs, and customers of MLH's ED.

We also interviewed the head nurse to get better insights on the problems faced in the ED. It enabled us to develop some assumptions that we further confirmed by designing and presenting a 5-point Likert scale survey to 20 staff members. It aimed to show their level of agreement on matters such as the considerable noise level or the effectiveness of the communication. Figures 3,4 and 5 show the most important results of the survey. Then, we developed a list of CTQ characteristics determined by the voice of the customers i.e. the ED staff as well as observations collected before, these CTQs were then used as KPOV, to be measured through controllable KPIV.

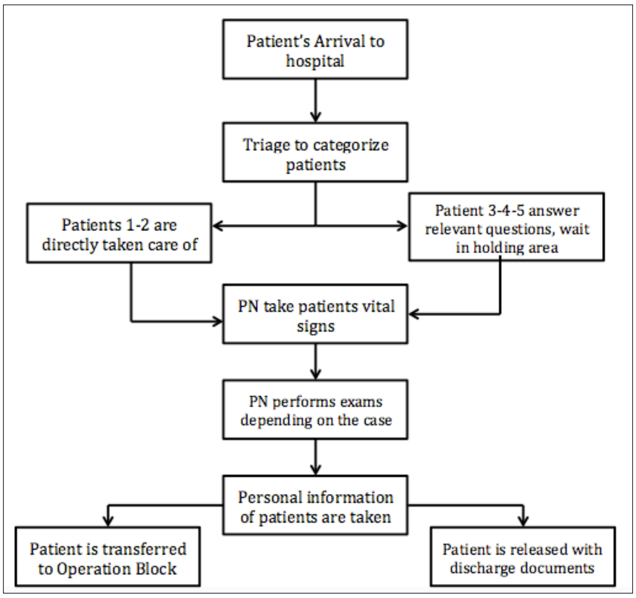

Fig. 1. Patient Flow in the ED

B. *Waiting Time Study*

Also, in order to study the waiting time of patients in the ED, we measured the extent of this issue by taking the arrival times of the patients and their admission times to a room over month of September 2019. We then placed the results in the pivot table in an Excel spreadsheet and computed the waiting times being the difference between admission times versus arrival times, and decided to use the most crowded day.

We then plugged our values into Input analyzer to determine the different distributions we have for inter-arrival times. After that, we decided to simulate our model by using ARENA with the assumptions listed in Table I.

TABLE I. ASSUMPTIONS MADE IN DESIGNING THE ARENA MODEL

Variables	***Values***
Number of Rooms	13
Number of nurses	10
Number of physicians	1
Treatment Time Distribution (by nurses) (in minutes)	Uniform~(10,20)
Treatment Time Distribution (by physicians) (in minutes)	Triangular~(10,20,45)

We first added a create module for patients' arrivals where inter-arrivals follow an exponential distribution with rate 23.33 minutes, then created the triage process where patients are filtered. A decision module was added with a 2-way chance with probabilities 0.33 for critical patients and 0.67 for non-critical patients; if the case is a non-critical patient they will be transferred to the waiting room and delayed.

Then we created a virtual process to input a priority queuing feature for patient with critical case. After that, another decision module was added with an N-way by condition for room occupation (idle/busy) or not; if all the rooms are occupied, the patient will return to the queue in the virtual process.

In the "room", the patient is first seized, then goes through two processes, first is the nurse treatment process following a uniform distribution with parameters (10,20) followed by the physician treatment process following a triangular distribution with parameters (10,20,45).

Finally, after being released from the room, the patient proceeds to the checkout process and exit the system.

We decided to take a 24-hour run length to be replicated 10 times. The reason for that is that we considered having a full day and we wanted to have enough replications to get more accurate results.

C. *Noise Level Study*

Furthermore, noise level is a very important KPOV to measure in ED's. In fact, noise generation has repercussions not only on the staff member's ability to focus, but on the comfort of patients as well. Therefore, we conducted a noise study in MLH's ED, focusing on the central desk. We first calculated the number of samples (n) needed for our hypothesis testing; mathematically and graphically using the Operating Characteristic (OC) curves. The below equations were used:

$$n = \frac{(z_\alpha + z_\beta)^2 \times \sigma^2}{\delta^2} \tag{1}$$

$$d = \frac{\delta}{\sigma} \tag{2}$$

Where:

n: Number of samples

z_α: z-value of type-I error α

z_β: z-value of type-II error β

σ: The standard deviation of the data

d: Effect Size

δ: Minimum shift in the mean in order to detect a change

After estimating the sample size, we visited the ED during four days in a week at different times of the day so our data would be random. And using a sound level meter we measured the maximum noise intensity (in dB) for over a 15-minute time interval. We then used SPSS software to analyze the data statistically. In defining the null hypothesis and alternative hypothesis, we have set $\mathbf{\mu_0}$**= 72 dB** because it is the standard mean noise level required in hospitals, according to the Joint Commission International (JCI). We then computed the p-value to test our hypothesis.

We also constructed a control chart shown in Figure 5 to detect the presence of out-of-control points. As we were not able to take a lot of measurements, and because we can subgroup our samples we opted for an X-MR (moving range).

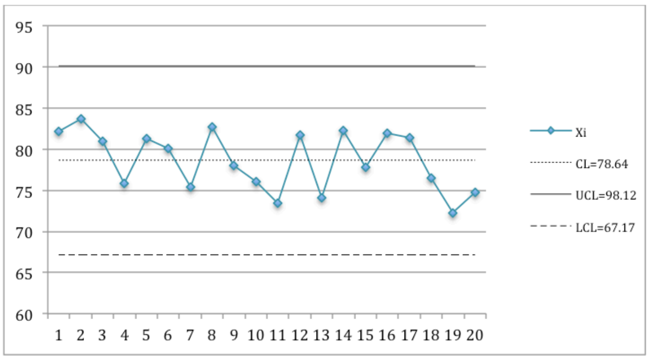

Fig. 2. X-MR Control Chart

V. Results

A. Interviews And Surveys

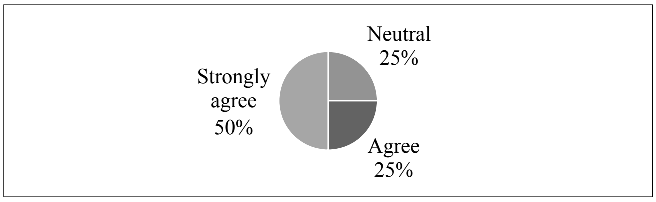

Fig. 3. Results for statement: "The central desk generates a lot of noise"

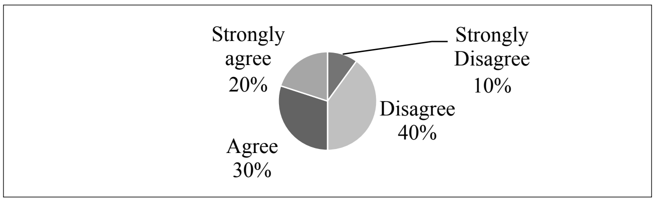

Fig. 4. Results for statement: "The communication between the staff members is effective"

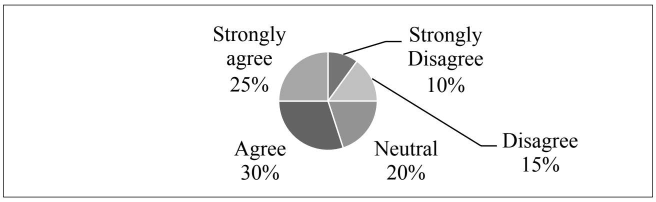

Fig. 5. Results for statement: The rate of patients leaving the hospital due to the lack of available beds is high

B. Root Cause Analysis

We constructed a fishbone diagram to carry out a more thorough analysis and to better visualize the root causes of the high waiting time at the ED. Concerning the "Medical Staff", their poor shift management results in a same schedule for peak and non-peak hours and thus to situations of understaffing. In addition, the lack of trainings provided to the medical staff as well as the lack of conformation to medical report writing standards, lead to delays in preparing the tools, equipment and reports. Another main cause contributing to the highest delay is the "Process" occurring in the ED, notably the delay in insurance approval due to slow automated systems. Also, since the ED lacks of fast-track system for minor injuries and triage nurses are understaffed at all times of the day; the triage is indeed inefficient. Another major problem is the repeated and unnecessary work performed on patients due to miscommunication resulting from incomplete medical reports and illegible handwriting. Regarding the "Environment", aside of limited capacity of beds in the ED, we realized while analyzing the facility maps, that we should focus on improving its layout because of the impractical location of the laboratories that most of the patients visit for extra examinations.

C. Waiting Time Study

The results of analyzing the collected data in a spreadsheet showed a maximum average waiting time of 33.32 minutes and a maximum number for patients reaching n= 66 during the 10 am to 11 am timeslot.

As for the simulation, we found that the model we developed with two physicians instead of one decreases the waiting time of the patients. In fact, in the initial model that represents the current situation as it is, the total time in the system for not critical and critical patients was 196.65 min and 155.54 min on average respectively whereas in the new model these values were 95.1 min and 64.678 min on average respectively. In addition, the maximum number of patients slightly increased with our modification; this could lead to increased profit.

a) Solutions for prolonged waiting time

To address the issue of high waiting times, we revised the staffing patterns and tried adapting the staff to peak demands by forming a "Pool Nurses" team. This team consists of nurses who usually operate in other departments notably the intensive care unit and cardiac care unit. This redistribution is expected to be beneficial at peak times at the ED. The "Pool Nurses" would already be performing their normal shifts at their assigned department, which should be their priority, but could receive an emergency call to help the ED in cases of patient overload or shortage in personnel. Moreover, the problem of understaffing can be solved by line balancing the system i.e. optimizing the number of physicians. Specifically, we studied the "Doctor on call" list and focused on prioritizing physicians with dual specialty to and maximizing their availability at the hospital, especially at peak hours. This way, physicians will be able to address several cases, instead of two distinct physicians for each case. Another alternative, is designing a separate "post emergency room" that accommodates stable patients who either have already been diagnosed but still need supervision or medications, or are waiting to be transferred to a room.

D. Noise Level Study

a) Sample Size

Mathematically, using (1)

$n = 17.46 \simeq 18$

Using the OC curve with $\alpha=0.05$ and when $\beta=0.10$ and using (2) for $\delta = 3$ and $\sigma = 4.393$, we obtain → n = 20

Thus, we decided to take a sample size of 20 to have more accurate results.

b) p-value Test:

p-value = 0

$\alpha = 0.05$

p-value < α

We reject H_0 using the p-value Test.

As the null hypothesis H_0 was rejected, we had the evidence that the sound level at MLH does exceed the mean noise level standard in hospitals.

c) X-MR control chart

In fact, the 20 noise-level measurements seem to be within the control limits of the X-MR control chart. However, with a CL of 78.64 dB, it is clear that most of the points are above the standard mean noise level required in hospitals, which is of 72 dB according to JCI. Along with the hypothesis testing, this proves the necessity of finding solutions to decrease the noise level in the ED.

d) Solutions for high noise level

Some industrial engineering solutions that came to our minds are:

· Behavioral modifications using public indicators; for instance, posts in every room reminding to keep voices down and cellphones on mute and a device called the

"Yacker Tracker", a more or less of a Kanban solution, will help remember to keep quiet and be aware of the noise level. This device functions similarly to a road sign as it flashes: Red light when the noise level is very elevated (in our case higher than 72dB) ,Orange when the noise level starts escalating ,Green when the noise level is acceptable.

· Educational systems and trainings including discussions about the negative impacts of high noises level; this is a way of continuous improvement or Kaizen.

· Using of sound absorbing materials, applied on the walls, floors and ceiling of the ED. Materials also have to fall within the health and hygiene policies. The current floor of the hospital is composed of four layers in this order: concrete slab, fine gravel layer, mosaic tiles and antistatic vinyl. The latter's purpose is to reduce the accumulation of static electricity thus dissipating the damp coming from the air. As industrial engineers this is out of our scope of study so we decided not to further research it.

· Filtering of the admissions in the ED based on seriousness of the case and availability, an optimization of the number of nurses and physicians using ARENA and the limiting of the number of patient's family and friends' admissions. These approaches will solve the issue of overcrowding.

· The optimization of the layout of the ED, moving away high noise level area from each other, such as the waiting room and the central desk.

I. Discussion and Conclusion

In this project, we were able to use a lot of industrial engineering tools to come up with solutions to problems that put at risk the operation of MLH's ED, being one of the most dynamic and fast-changing areas of the hospital. In fact, by establishing KPIV and KPOV, we were able to identify the most important CTQ characteristics to study in ED. For that, we tackled both the noise-level and the waiting time in order to optimize the processes and flows of this department and maximize the satisfaction of both the patients and the staff members.

Our study suggests that on average the noise level in the area is rather high and this indeed weakens the ability to focus of the staff members as mentioned in literature. In order to tackle this issue, we provided MLH with numerous solutions such as the use of the Yacker-Tracker device that gives a signal when the maximum noise level is reached, and simple approaches such as limiting the number of entries and simple posts. Additionally, we studied the waiting time of patients before getting admitted to a room in the ED and simulated the process when adding another physician to the ED. The results obtained show a drastic decline in waiting time as it decreased by almost half. Therefore, we intend to advise MLH to organize a line balance of "doctor-on-call' and use automated documentation for reports among other resolutions. It's important to note that we are currently studying the economical feasibility of all our solutions before recommending them to MLH. Some of these require the restructuring of staff and therefore changing the current schedules of the nurse, physicians and doctors in charge in the hospital and we are currently working on optimizing those schedules.

Last but not least, we plan to use the SLP method to propose a new facility layout that would optimize the efficiency of the processes and flows. Also, using ergonomic principles will enable us to enhance the safety of patients and nurses in the ED.

This study has some limitations that are worth mentioning. In fact, although we tried as much as possible to gather random measurements to minimize bias, we never happened to be at the hospital in a crisis situation when some values peak. In addition to that, our access to the hospital was very often obstructed due to the recent event happening in Lebanon and to time restrictions. If we had more time we would have taken more measurements to maximize the accuracy and conformance to the actual ED system. Another limitation is the lack of literature on the study of hospitals' EDs noise levels particularly. However, were able to perform our analysis by relying on approaches done in studies in other hospitals' departments.

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