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ABSTRACT

Emergency departments' capacities to deal with a patient surge (the number of patients increases in a short period of time) play an important role in preparedness for natural or man-made disasters. This paper examines how emergency departments could improve their capacities by optimizing the workflow. A framework is proposed to reconfigure the workflow to improve capacity while maintaining treatment equality. Our results show that reducing lower priority processes and combining originally separate processes can shorten patient total waiting time in the emergency department.

Keywords

Emergency department, simulation, extreme event, patient surge.

1 INTRODUCTION

We are facing an increasing number of natural disasters (e.g., earthquake, storm, and hurricane) and man-made disasters (e.g. terrorists) which usually result in human casualties and demand immediate and effective medical care. Therefore, the effective functioning of a healthcare facility is critical to the mitigation and recovery from any disasters (Paul et al. 2007).

However, the Healthcare industry has been criticized for its high cost and low efficiency. Emergency departments, in particular, have been struggling with limited resources and an increasing number of patients. Previous studies show that the capacities of most emergency departments could not satisfy the need if a major disaster occurred, and some emergency departments have almost reached their maximum capacities even in normal situations (DeLia 2005). Thus, it is important to seek methods to improve the capacity of emergency departments to meet the requirement.

Simulation technique is widely used in healthcare settings. The strength of simulation lies in its ability to help decision makers study 'what-if' scenarios. Thus it is very suitable for emergency department capacity planning where the relationships among the variables are usually non-linear and difficult to formulize using ordinary modeling methods. Previous healthcare simulation studies focus on how to optimize the patient flow in normal situations (See Jun et al. (1999) for a comprehensive literature review), but few studies have examined how the emergency departments can be prepared for a patient surge in an extreme event. To address this gap in the literature, we explore the relationship between workflow and hospital capacity. Particularly, we attempt to answer the following research questions: Given the limited budget and resources, how can a hospital improve the emergency department's capability to deal with a patient surge during an extreme event by reconfiguring its workflow while maintaining its treatment quality?

The rest of this paper is organized as follows: we first review the literature on healthcare simulation, and then propose a framework to reconfigure the workflow of an emergency department to deal with a patient surge during a disaster situation. An algorithm on workflow configuration is also presented. Next we apply this framework to a local emergency department and show some preliminary results of the effect of workflow reconfiguration on the emergency department capacity. Finally, the implications of this study, as well as its limitations and future research directions are discussed.

2 LITERATURE REVIEW

The simulation method is widely used in all kinds of healthcare systems to assist in decision-making. Draeger (1992) develops a simulation model to evaluate process performance in terms of patient waiting time and treatment time as well as the staff and facility utilization rate. In particular, the author investigates how nurse staffing could affect the patient flow. Eldabi et al. (2007) propose a general framework to integrate simulation models at different levels. Their framework contains three modules: requirement module, skill and resources module, and method module. Sinreich et al. (2005) propose an approach which aims to improve the flexibility and compatibility of the simulation tool. They classify the emergency room into four basic types and patients into eight types. The similarities and variances of patient flow among different types are analyzed and then applied to the development of a general simulation prototype.

Data collection is critical for the validity of the simulation results, and the data collection methods are discussed in literature. In addition to traditional data collection sources, such as hospital reports, logs of Ambulance authority, observations and interviews with hospital personnel, White (2005) identifies a alternative data source for healthcare simulations -- the healthcare care cost and utilization project, which owns five databases including the Nationwide Inpatient Sample (NIS), the Kids' Inpatient Database (KID), the State Inpatient Databases (SID), the State Ambulatory Surgery Databases (SASD), and the State Emergency Department Databases (SEDD), with data from hospital-affiliated emergency departments. These databases could be used as complementarities to traditional data sources. Amini et al. (2007) adopt a creative method for data collection-- they use Radio Frequency Identification (RFID) as a data source in their simulation model development. RFID is a technology to track physical items such as raw materials and products. In their study, the patients wear RFID devices when they begin their stay in hospital. Their locations and stay time are recorded during the period of being in the hospital. Their study shows that RFID can work well with other technologies in the healthcare setting, can capture the patient flow accurately, can enhance the data availabilities, and can improve data collection efficiency significantly. A RFID-based simulation framework is proposed based on their novel data collection methods.

Recent studies on healthcare simulations are bringing in other operation research methods. Compared with traditional simulation methods, which aim to reproduce the behavior of the healthcare systems and assess their performance, the new stream of studies use the simulation to generate observations and estimate the values of objective functions and constraints, which are usually nonlinear functions and hard to solve (Angelis et al. 2003).

Oddoye et al. (2009) combine simulation and goal programming to facilitate resource planning with multiple objects in a medical assessment unit. Goal programming is used in their study to formulate object functions and constraints associated with it. Objectives are prioritized by assigning a weight to each of them. Simulation is used to analyze bottlenecks and provide the solutions to the goal programming problem. Their work demonstrates how goal programming and simulation could be used to handle multi-objective decisions in the healthcare context.

Ahmed et al. (2008) propose a simulation optimization method to optimize the allocation of resources such as doctors, nurses, beds and medical instruments while shortening the parents' waiting time in an emergency department. Their formulation includes two constraints: budget constraint and average waiting time constraint, both of which are in stochastic form and could only be evaluated by simulation. To reduce the number of iterations, this paper presents a two-phase method to restrict the scope of searching for feasible solution. The results show that their solution significantly improves the patient throughput.

Angelis et al. (2003) also combine simulation and optimization methods to determine the optimal configuration of a healthcare system which could minimize the patient total time in the hospital under the budget constraint. Their method includes four steps: on-line survey, system simulation, estimation of the target function, and optimization.

3 THE WORKFLOW AND EMERGENCY DEPARTMENT'S CAPACITY

Previous studies on emergency department capacity usually only consider resource allocation. However, through interviews with personnel in hospitals, we find that during a disaster situation, some patient treatment processes might be rearranged to increase the emergency department's capacity, shorten the waiting time and save lives. For example, in a normal situation, before they received treatment, the patients' insurance information is collected and assessed by the clerk, which usually takes 10 minutes. However, in a disaster situation, such a process could be skipped. Reconfiguration of the workflow can reduce the patient total time in the hospital in two ways. First, reducing the number of non-critical processes can decrease the total treatment time. Second, the resources released from the skipped processes can be used in other processes and thus reduces the patient waiting time.

On the other hand, reducing the necessary processes may compromise treatment quality. Therefore, the trade-off between reducing the patient waiting time and maintaining the treatment quality needs to be considered during a disaster. In this

paper, we propose a simulation-based framework to reconfigure workflow and assess the configuration's performance. The details of each step in this framework are discussed in section 3.1.

3.1 A framework for workflow reconfiguration

The framework outlines the procedures of workflow reconfiguration in the emergency department and consists of the following five steps.

Step 1: Data collection

In order to develop and validate the simulation model, the following data are needed:

- Arrival rate of patients

- Patient treatment time

- Historical data on extreme events in the local area

The arrival rate of patients and the patient treatment time are used to estimate the distribution of the processes in the simulation model and to set corresponding parameters. Historical data on extreme events are used in the next step to estimate the patient surge in a disaster scenario.

Step 2: Risk analysis

To predict the patient surge in the disaster, the possibilities and severities of the major disasters are estimated. The prediction of natural disasters is based on historical data, and the prediction of man-made disasters can be made based on the reports of law-enforcement agencies.

Step 3: Business processes classification

In this step, we ask the personnel to set the priorities for all the processes in the emergency department and enumerate all the possible configurations of the emergency department's treatment processes, including the allocation of staffing and resources. Processes with low-priority could be skipped under certain circumstances, such as during a disaster. Processes with high-priority are critical to the patient treatment and cannot be skipped.

Step 4: Simulation and optimization

Simulation can be used in this step to evaluate the performance of the emergency department under different process configurations in terms of the patient throughout, patient waiting time, and resource utilization rate. The process configuration which has the largest number of high-priority processes and meets the waiting time constraints is the optimal solution. The algorithm of the process selection and configuration is presented in the session 3.2.

Step 5: Configuration implementation

Once the disaster occurs, the emergency departments can reconfigure their processes and rearrange their employees based on the optimal solutions obtained from previous steps.

3.2 An algorithm for process selection and configuration

In this section, we model the process selection and configuration problem and propose an algorithm to solve it. Consistent with previous studies(Angelis et al. 2003), we use patient total time in emergency department and waiting time as two constraints. Patient waiting time is a key factor affecting their satisfaction with the emergency department. In addition to requesting a high-quality treatment, patients also desire prompt attention, i.e., not having to wait too long.

The emergency department has N processes $(x_1, x_2, \ldots x_N)$ in normal situation which can be classified into T (T<=N) clusters $G_1, G_2 \ldots G_T$, and the processes in the cluster i(1<=i<=T) has the same priory P_i (larger number indicates higher priority). We can rearrange the sequence of the cluster to let $P_i > P_j$ if i>j. Let's assume that the processes x_i's with priority equal to or greater than p (p is the priority threshold) are the core processes, i.e., that processes cannot be skipped in any cases. Let's assume that the processes in cluster G_n are the core processes having the smallest priority, the number of patient visits in a disaster is expected to be M , the maximum waiting time is set to be B_1,and the maximum total time in hospital is set to be B_2,. Then the processes configuration selection problem can be formulated as follows:

$$\text{Min } \Sigma \, P_i * |S_i|$$

s.t. $f1((G_1-S_1),(G_2-S_2),\ldots(G_{n-1}-S_{n-1}),G_n,G_{n+1},\ldots G_T,M) <= B_1$

$\qquad f2((G_1-S_1),(G_2-S_2),\ldots(G_{n-1}-S_{n-1}),G_n,G_{n+1},\ldots G_T,M) <= B_2$

Where S_i is the subset of G_i and all processes in S_i will be skipped in the disaster in order to reduce the total time and release the resources associated with it, while the processes in the set (G_i-S_i) will be retained. Let $|S_i|$ denote the number of processes in S_i, and f1 and f2 are the function of total waiting time and total time in the emergency department, respectively. The form of f1 and f2 are not specified in this model because they are very complicated and their values would be obtained through simulation. The goal of the model is trying to reduce the patient total time and waiting time in the emergency department to a reasonable level while maintaining the treatment quality as high as possible (i.e., we try to keep the processes with higher priority in the configuration). If there is no optimal solution to the model, the emergency department might have to request external resources to handle the patient surge. Otherwise the patient surge can be handled without extra resources. This process configuration optimization problem could be solved through the following algorithm which consists of seven steps.

1. Let $T_1 = \{x_p, x_{p+1}, \ldots x_{p+r}\}$ be the set of non-core processes with the highest priority in the current process configuration. If $|T_1|=0$, then go to step 6; if $|T_1|=1$, then Let $x_{skipped}=x_p$ and go to step 5. If $|T_1|>=2$, then go to the next step.

2. Let $T_2 = \{x_q, x_{q+1}, \ldots x_{q+s}\}$ be the set of processes in T_1 with the longest processing time. If $|T_2|=1$, the let $x_{skipped}=x_q$ and go to step 5; if $|T_2|>=2$, go to the next step.

3. Let $T_3 = \{x_m, x_{m+1}, x_{m+t}\}$ be the set of processes in T_2 with the largest amount of resources associated with them. If $|T_3|=1$, then let $x_{skipped}=x_m$ and go to step 5; if $|T_3|>=2$, go to the next step.

4. Assume x_n is the process with the smallest index in T_3, then let $x_{skipped}=x_n$

5. Remove process $x_{skipped}$ from the configuration and run the simulation. If the solution is feasible, then go to step 7; otherwise go the step 1.

6. Stop. The emergency department's current capacity cannot meet the patient surge during a disaster.

7. Stop. The current solution is the optimal solution.

4 A CASE STUDY

In this section, we apply our framework in a local emergency department to increase their capacity during a disaster situation and demonstrate how workflow configuration could reduce patient total time in emergence department.

4.1 System description

Our research is conducted in an emergency department located in Western New York, which is open 24 hours a day, seven days a week. The flow chart of this emergency department is shown in Figure 1 and discussed below.

Patients arrived in the emergence department in two ways: either were transported by ambulances or walked in on their own. The patients first checked in at the reception where their information was collected, and then waited in the waiting room till their names were called. The following step is triage interview conducted by triage nurses or triage technicians, who would determine the patients' ESI (Emergency Severity Index) level based on a five-level classification system. Patients at different ESI level would go through different processes. Patients at ESI level five have minor problems and stable condition, and were routed to ACU (Alterna Care Unit) where they would take ER (Emergency Room) nurse assessment, ER technician assessment and initial treatment. Patient at ESI level three and four were routed to ICU (Intermediate Care Unit) where they would take either emergency physician assessment or senior resident assessment in addition to all the processes included in ACU. Patients at ESI level one and two have the most severe conditions and were routed to CCU (Critical Care Unit) to take all the processes in ACU and additional emergency physician assessment. After the initial treatment (for ACU patients) or emergency assessment (for ICU and CCU patients), the doctors would determine whether the patients needed to take a lab test, CT scan diagnosis, or X-ray procedure. If the patients did need such a diagnosis, they would have to wait for the availability of the facilities to take it, which is followed by the finial treatment. Otherwise they would receive their final treatment directly. Upon the completion of treatment, the patients were either admitted to hospital or discharged.
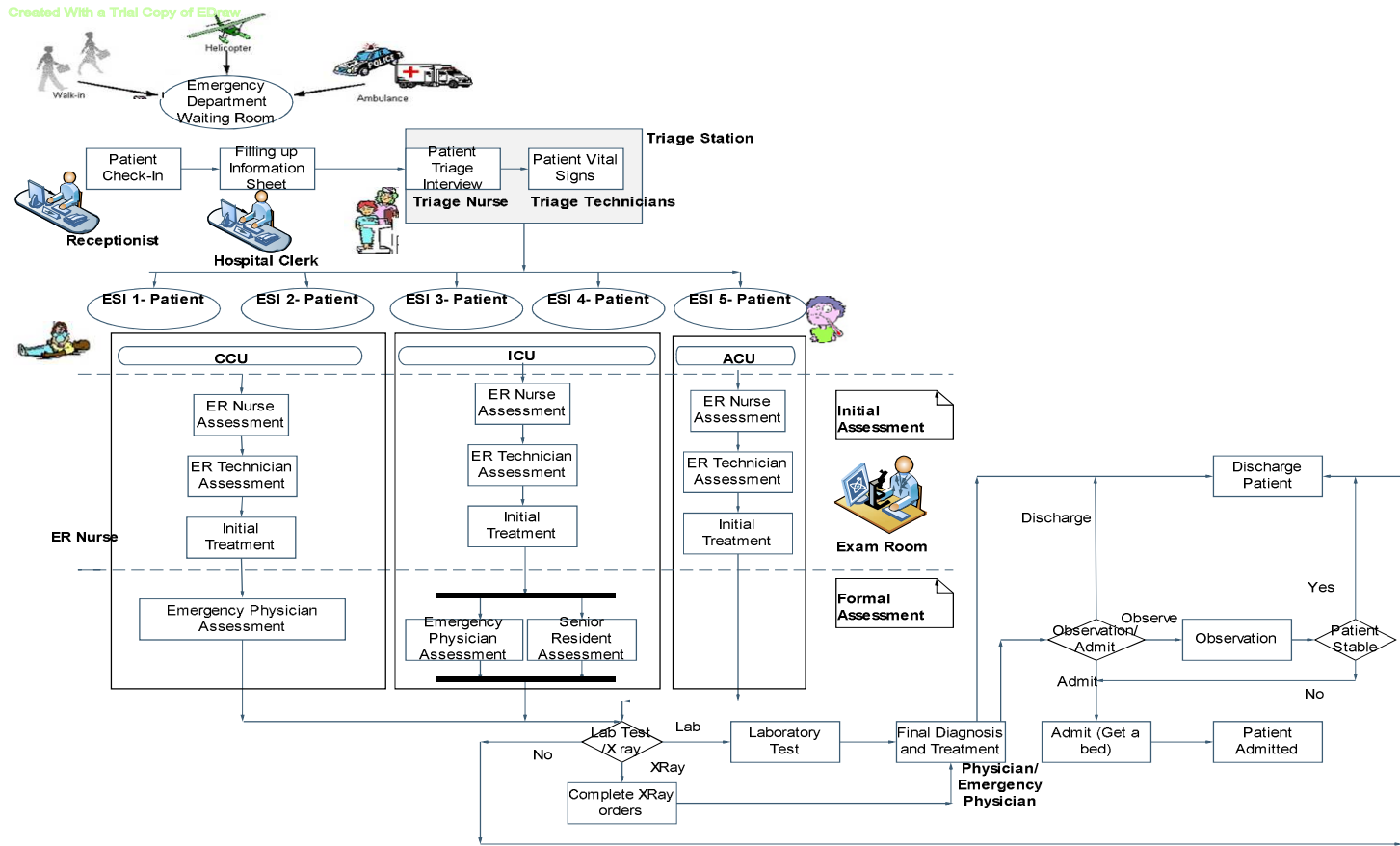
Figure 1 The flow chart of an emergency department

4.2 Data collection

In our case study, the data were collected through the observation of emergency department operations and interviews with the director of the emergency department. A graduate student spent a week in the emergency department to observe and record patient flows. The director of the emergency room checked and confirmed the records and gave the estimated number of the patient arrivals during the night (which was not recorded by the student). Also, the director was asked to recall the number of patient arrivals during a snow storm which occurred two years ago and is the most recent disaster affecting this local area.

The data collected include the patient arrival time, numbers of nurses, doctors, beds, and instruments for three types of labs (blood, X-ray, and CT scan), and the treatment time for each process. The priorities of processes in this emergency department are classified into three groups: low, medium, and high. Financial registration and initial assessment processes are identified as low-priority processes which could be eliminated from the workflow to couple with the disaster, and accordingly the resources associated with these two processes are released to other processes.

4.3 Simulation experiment

Based on the data we collected, a simulation model was built using Arena 10.0 (Kelton et al. 2007). The parameters used in the simulation model are shown in Table 1. We conducted the simulation experiments for three workflow configurations. The first configuration includes all the processes. The second configuration excludes the processes with low priority (financial registration and initial assessment) and allocates the resources associated with them to formal assessment and CT scan processes (which are bottleneck process in the first configuration). In addition to reducing the number of processes in the second configuration, additional resources are used in the triage process (adding one nurse), formal assessment process (adding three doctors and two nurses), and CT scan test process (adding two CT scans) under the third configuration. The patient total time in emergency department was used as the performance measure to compare these three configurations. For

each configuration, we varied the patient arrival intervals and collected corresponding patient total time from simulation output. For each combination of the parameters, five simulation runs were conducted with a seven-day warm-up period.

Table 1. Service time, resources and priority of the processes

Processes	Distribution(minutes)	Resources	Priority
Reception	Triangular(1.8,2,3)	One receptionist	Medium
Financial Registration	Triangular(12,15,17)	Two nurses	Low
Triage	Triangular(3.8,5,8.8)	Two nurses, two triage room	High
Initial assessment	Triangular(8,9,12)	Two nurses, two physicians, five beds	Low
Formal assessment	Triangular(9,13,16)	Two nurses and two physician, five beds	High
CT scan	Triangular(70,75,80)	Two CT scan rooms	High
Blood test	Triangular(8,10,12)	Six blood test labs	High
X-ray	Triangular(25,30,35)	Four x-ray rooms	High
Treatment	Triangular(80,90,95)	Three nurses, eight physicians, seventeen beds	High
Documentation and discharge	Triangular(24,30,41)	One nurse	High

4.4 Preliminary results

The results are shown in Figure 2. We can see that the waiting time is reasonable in the original workflow (with all the processes) when the patient arrival rate is at a low level (i.e., when arrival interval is longer) , but the waiting time increases rapidly as the patient arrival rate goes up, which indicates that the original workflow cannot handle the patient surge. In contrast, the waiting time in the workflow without low priority processes increases relatively slowly as the patient arrival rate increases, showing process configuration does improve the emergency department's capacity and can be used to deal with the patient surge in the early stage of a disaster. Our results also reveal that combining additional external resources and workflow reconfiguration could significantly improve the emergency department's capacity, indicating that obtaining external resources is critical to emergency department during a disaster situation.
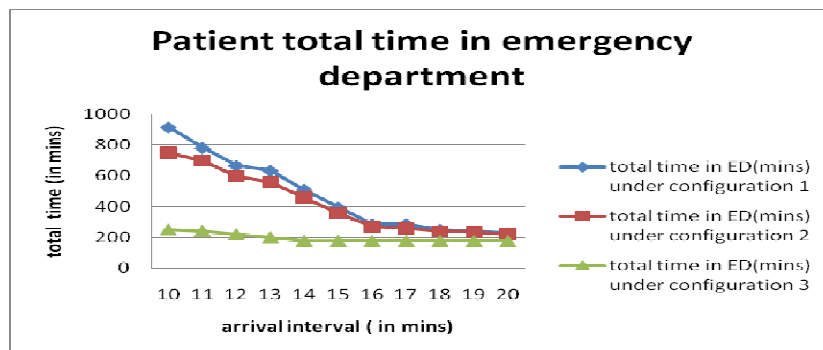

Figure 2: Patient total time in emergency department under three workflow configurations

5. IMPLICATIONS

Our study has several implications for the management of an emergency department. First, processes reengineering provide a viable method for improving the emergency department's capacities by reducing the low-priority processes. When extreme

event occurs, the emergency department can increase the patient throughput while maintaining the treatment quality at a moderate level by taking full advantage of their potential capacities. Second, emergency departments can foster their potential capacities by cross-training their employees, especially the nurses. The employees who are competent for more than one job can easily shift from their original position to a new one if such a transition is needed. Third, the design of emergency department should take into account the possibility of processes rearrangement. For example, we would suggest that the resources for low-priority processes should be put adjacent to related higher-priority processes, so that once those low-priority processes are determined to be skipped during a disaster, their associated resources could be released and reused in higher-priority processes with little adjustment. Fourth, external resources play an important role in emergency department's capacity improvement. Hospitals should be able to identify the external sources to obtain critical resources in preparedness for large-scale disaster.

6. CONCLUSION AND FUTURE RESEARCH

Patient surge has become a big concern in the course of disaster preparedness. To address this issue, we proposed a simulation-based framework to reconfigure the workflow to improve the emergency department capacity. This framework is applied in an emergency department to deal with the snow storms which have struck the local area heavily. The preliminary results show that the workflow reconfiguration can decrease the patient waiting time in emergency department. This framework provides insights into the relationship between the workflow and the system's capacity, and could serve as a tool to facilitate the hospital's disaster planning.

Our work makes two contributions: First, using simulation techniques, we explore how to deal with the patient surge during a disaster, an important issue but paid less attention in previous studies. Second, we provide a new perspective – process reconfiguration- to improve the capacity of the emergency room.

Since the work presented in this paper is still in progress, the full results are not presented. The two research directions we are intending to pursue in the future are as follows: First, a decision support system can be developed based on the framework and configuration selection algorithm proposed in this paper to prepare the emergency departments for the disasters and assist them in redesigning their processes. Second, the enumeration algorithm is used in this paper to search for the optimal solution, but it can only be used in emergency departments with fewer processes. If the number of low-priority processes increases, such an algorithm will become inefficient. Therefore, an advanced algorithm is needed to improve the efficiency and shorten the searching time for the optimal solution.

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