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EMERGENCY DEPARTMENTS NURSE ALLOCATION TO FACE A PANDEMIC INFLUENZA OUTBREAK

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ABSTRACT

This study proposes a nurse allocation policy to manage patient overflow during a pandemic influenza outbreak. The objective is to minimize the number of patients waiting in queue to be treated for the virus while maximizing patient flow. The model is built using ARENA simulation software and OptQuest heuristic optimization to propose various combinations for the number of nurses needed for healthcare delivery. Results are compared with a basic setting that closely emulates the resources and components in a Veteran's Hospital. The proposed method significantly reduces the number of patients waiting in queue (between 4 to 37 percent on average) for the simulated zones. ARENA process analyzer was used to evaluate various scenarios for nurse availability. Sensitivity on the results for these changes was tested by increasing the flow of patients through the system.

1 INTRODUCTION

According to many scientists and epidemiologists, a new influenza pandemic outbreak is unavoidable. Experts agree that it is not a matter of whether or not it will occur, but when it will occur (Roche 2007). The word "pandemic" has been defined as a disease that emerges when a new virus appears, and then spreads easily from person to person worldwide. Pandemic occurs after three conditions are met: first, the emergence of a new flu strain; then, the ability of the strain to infect humans and cause serious illness; and finally, the easily human to human spread (DHHS 2007).

According to Overby, a pandemic occurs every 10 to 40 years. Thus, there is a constant threat of a pandemic influenza breakout to occur. For that reason, it is imminent for healthcare systems to know how to proceed, and how to be well-prepared if events of this nature occur (Overby 2005).

Due to drastic increase in expected demand of patients to hospitals services, especially emergency to departments (ED), it is vital for hospital management to develop a reliable plan to face events of this magnitude. ED environments possess a limited number of resources (i.e., nurses, physicians, pharmacists) for the everyday routinely requirements. However, under an influenza pandemic incidence, the impact on patients' demand and the complexity of the cases could become overwhelming enough to result in a chaotic system impossible to operate.

In this research, a simulation modeling approach is developed to enhance understanding of ED's intricacies, as well as nurse allocation and utilization. In general, simulation modeling is an adaptable and informative tool, and it can be used in assisting decision makers to better strategize when allocating limited staff personnel to critical tasks.

Simulation has been used in emergency department for maximizing capacity (Baesler et al. 2003), assisting expansion plans (Wiinamaki and Dronzek 2003), reducing length of stay (Samaha et al. 2003), an to assess indoor airborne infection risks (Liao et al. 2003). Moreover, healthcare simulation has grown in popularity because it can be used for dynamic as opposed to static analysis (Eldabi and Paul 2001).

This paper presents a computer simulation model that captures the dynamics on an ED during a drastic increase of patient demand over a short period of time (12 weeks). The research focuses on modeling only the allocation of nurses. Various scenarios are explored and a set of alternatives are generated to determine best combination of resources that increases patient flow and decreases the number of patients waiting.

2 PANDEMIC INFLUENZA BACKGROUND

There have been three major pandemic incidences in history which have left thousands of deaths worldwide. These

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include the 1918 Spanish Flu, the 1957 Asian Flu, and the 1968 Hong Kong Flu.

About one third of the world's population (approximately 500 million persons) got infected during the Spanish Flu. During the Asian Flu 69,800 people in the United States alone died, and the Hong Kong Flu left a total of 33,800 deaths (DHHS 2007). The Spanish Flu is known as the most fatal pandemic event in history due to the high death rates specially among young adults and high risk groups (Taubenberger and Morens 2006). Figure 1 illustrates mortality rates among the different age groups during the years before the Influenza (inter-pandemic period) and the Spanish influenza itself.

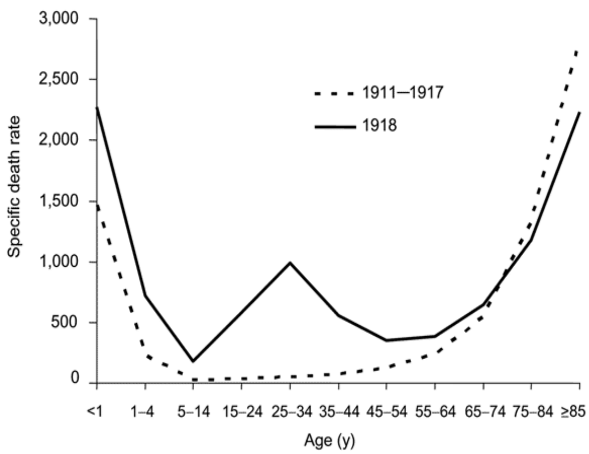

Figure 1: United States 1911–1918. Pandemic and Inter-pandemic periods specific death rates (Morens and Taubenberger 2006).

According to the Federal Department of Health and Human Services, "Past influenza pandemics have caused symptomatic infection in about 30% of the U.S. population. Thus, in the current U.S. population alone there would be almost 90 million illnesses, and many more persons would have asymptomatic infections." (DHHS 2007). Supplements on healthcare planning indicate that the estimates in terms of hospitalizations could be between 839,000 to 9,625,000 based on the 1957 and 1968 pandemic events. A total of 18 to 42 million outpatient visits and 20–47 million additional illnesses could be expected depending on the attack rate of infection during the pandemic. This concerns every part of the society and raises a problem that needs to be studied carefully to come up with strategies to face these type of situations.

3 PROBLEM STATEMENT

A large flow of patients is expected to access EDs during an outbreak. Thus, a pre-pandemic planning or a course of action is crucial to provide quality service, effective care to ill persons, and intelligent strategies that help prevent further spread of the infection.

According to pandemic protocols, once the outbreak occurs, hospitals must dedicate an exclusive area for patients with the pandemic virus. This area will be divided into five zones: triage, green, yellow, red and black (Davey et. al. 2006).

Given the limited availability of nurses (even during normal daily operations), this study explores how to efficiently allocate nurses to the different zones for improved ED performance.

4 MODEL DESCRIPTION

The following subsections describe the logic of the various components of the model. Figure 2 illustrates the process flow for a case of a pandemic influenza. Most of the information on the diagram and the assumptions on the data are extracted from a County-wide pandemic influenza drill held in Hillsborough County, Florida.

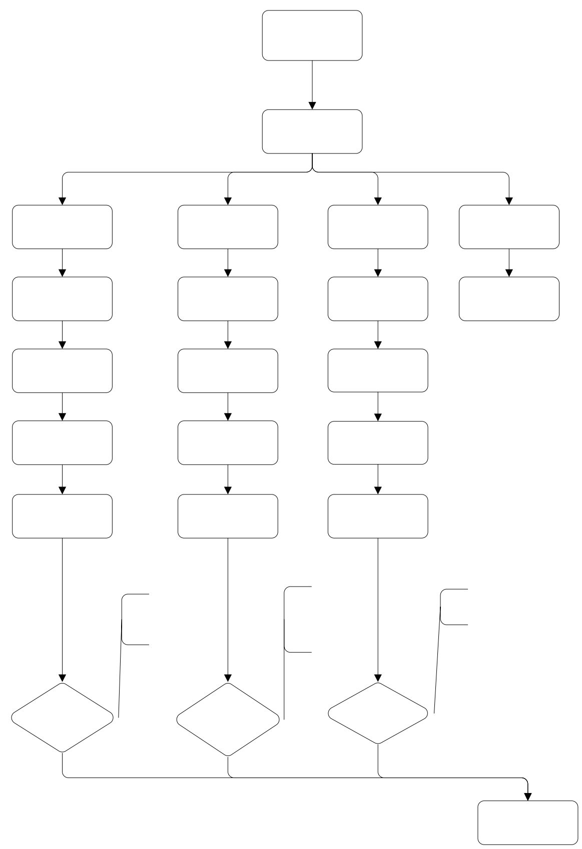

Figure 2: Process logic of a influenza pandemic scenario of a hospital.

4.1 Patient Arrival

. Assuming a 12-week outbreak it would be expected that the number of patients arriving to the ED during the first week would be small, but increasing over the subsequent six weeks. During the final six weeks patient arrival is expected to decrease. This assumption is based on the experience of previous pandemic influenza. Figure 3 shows the bell shaped graph for the patient arrival per hour during the twelve-week outbreak.

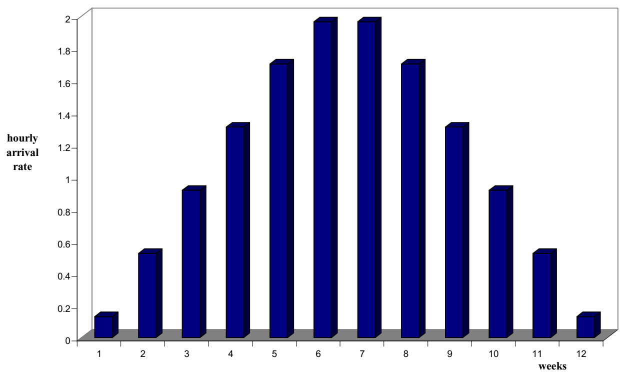

Figure 3 : Resulting arrival rates per week assuming a Poisson distribution using FluSurge 2.0 for the surge estimation during a pandemic influenza scenario.

FluSurge 2.0 is used to determine the arrival rate of patients to the hospital. FluSurge is a spreadsheet-based model which provides hospital administrators and public health officials estimates of the surge in demand for hospital-based services during the next influenza pandemic. The default values in FluSurge produce a 1968-type pandemic (Zhang, Meltzer and Wortley 2005). The resources available used as input for the FluSurge Model to estimate the surge for the hospital are shown in Table 1. ,

Table 1**:** Resources available according to the Veteran's Hospital Respiratory Infectious Diseases Emergency Plan (Farley 2006).

Resources available	
Nurses	54
Non-ICU Beds	281
ICU Beds	39
Number of Ventilators	84

4.2 Triage Process

The process is as follows. Potential infected patients arrive to triage process. Triage is a sorting process where nurses determine how ill a patient is. The patient is tagged with one color that represent one of the different zones where he or she can receive a proper treatment (these categories are red, yellow, green, and black).

The criterion of sorting a patient to the different areas depends on the severity of the symptoms that the patient exhibits, and the complexity or number of medical procedures that might be required (Vance and Sprivulis 2005). Patients with the most severe symptoms go to the red area. Patients in an advanced stage of the illness go to the yellow area, and patients with the least severe symptoms go to the green area. Patients that are beyond any medical help are taken to the black zone.

4.3 Follow Up Process

After the triage process, the registration is performed by a nurse while the patient waits to be treated in the area previously set to influenza pandemic infected patients.

The patient seizes a bed and waits to be seen by a nurse. The nurse decides if a consultant should be called to do conduct a more detailed examination of the patient. The physician might order more tests for the patient if needed. There is a delay attributed to this process. The consultant could also discharge the patient based on his expertise.

If the consultant orders tests, the patient will continue through the process of testing. The consultant or an authorized member of the staff can decide which type of treatment should be provided. If there is no need for a consultant, the patient is treated by the nurse who performs the first examination. Once the tests have been completed, there is a delay until a clinical decision can be made by the attending physician. The clinical decision determines illness level of severity and the treatment to be used.

The patient will stay in the systems while receiving treatment. After a period of time, the patient should improve and go home, or get worse and die.

5 MODEL DEVELOPMENT

This simulation model is developed using Arena 10.0 simulation software. The initial objective is to evaluate the system performance during a pick demand situation. Then, OptQuest for Arena is used to find the optimal allocation of resources in the different areas of the hospital.

The simulation model is divided in five sub-models. These five sub-models include:

- Triage Process
- Green Zone
- Yellow Zone
- Red Zone
- Black Zone

Every patient is considered an entity entering the model. A patient accesses the triage zone where he/she is processed by a nurse. The estimated time for the triage process is based on a triangular distribution with parameters 1.42, 2.75, and 4.5 minutes (Hupert, Cuomo and Neukermans 2003).

The patients are sent to one of the areas based on percentages. Since there is no historical data for these percentages, these estimates were made through consultations with experts familiar with the system, and previous simulation model for related demand cases.

The patient enters the zone that has been assigned in the triage process and follows a series of process or treatments as it is shown in the process flow in Figure 2. The activities carried and the time estimates for the follow up process performed to the patient in the different zones are based on a triangular distribution shown in Table 2.

Table 2: Processing times using a triangular distribution (Patvivatsiri 2006)

Activity	Red Area	Yellow Area	Green Area
Bedside Registration	(15,20,25)	(15,20,25)	(15,20,25)
Baseline assessment	(7,12,15)	(7,12,15)	(7,12,15)
MD evaluation (delay)	(15,25,40)	(8,15,30)	(5,15,25)
Final Nursing Treatment	(30,50,120)	(30,50,90)	(15,30,60)

The period of time the patient spends in the hospital depends on the speed of recovery. If the situation gets worse, then the patient should go to a different area to receive a more intense treatment.

Every area is categorized by the complexity or number of treatment a patient receives while he or she is there, and this determines how long the patients stays in the hospital. Therefore, a patient arriving to the red zone is expected to receive a higher number of treatments and stay longer than a patient going into yellow or green zones.

When the system has reached its maximum capacity, patients must be taken to other facilities according to the hospital policy for these cases. The capacity is limited by the number of beds and nurses.

5.1 Verification

The process of verification ensures that the computer programming and implementation of the conceptual model are correct (Sargent 2005). The techniques implemented in this project to verify the computer model with the conceptual model were:

- Different persons more familiar with the system from the VA's hospital were asked to check the computer model.
- A flow diagram was developed to describe the activities that are carried out through the hospital under these special circumstances (Figure 2).
- The computer model was animated to verify the behavior of the system.

6 SIMULATION RESULTS

The simulation model was run for 12 weeks, and results were analyzed. The model exhibited an overwhelmed system due to the large flow of patients accessing to the hospital. The most critical zones within the systems were the red and yellow zones. The results in terms of number of patients in different zones' queue length and nurse utilization for the starting system to be optimized is shown in table 3.

Table 3: Estimates for the number of patients waiting in queue and percentages for nurses' utilization in the different areas in the current system.

	Number of patients in queue for nurses		Nurse utilization (%)
	avg	max	avg
Green zone	<1	7	20%
Yellow zone	151.4	200	94%
Red zone	89.43	151	89.70%
Black zone	<1	<1	<1%

The yellow and red zones have the highest number of patients waiting since the activities carried through this zones are more frequent and complex. Also, patients stay in these areas more time. While more patient are admitted to these areas, the number of patients accumulates through time.

7 EXPERIMENTAL APPROACH

OptQuest software was used to find a more effective allocation of nurses to different areas. OptQuest is a search method capable of finding optimal or near optimal solutions to complex problems involving elements of uncertainty. The optimization method used by OptQuest evaluates the responses from the current simulation run, and integrates them with output from previous simulation runs to determine a new set of values for the controls. These are evaluated by running the Arena model (Rockwell Automation 2004).

The variables used for the optimization process were defined as the number of nurses for triage, red, yellow, green, and black area. The problem was described by selecting the objective of minimizing the number of patients waiting to be treated in different zones and the constraint was the total number of nurses available in the hospital to be allocated to different zones which is 54.

Using OptQuest the following policy was found based on five replications for each simulation, and the recommended number of nurses for each zone is:

- Red zone: 15
- Yellow zone: 26
- Green zone: 6
- Black zone: 2
- Triage area: 5

This allocation of nurses suggested by the model was utilized to re-evaluate the system. The new estimates for average and maximum number of patients waiting in queue are shown in table 4. The most significant improvements are seen in the red and yellow area; that is, the average number of patients waiting for treatment decreased by 37% in the red zone. Also, the maximum number of patients waiting in the yellow area decreased by 24% and 4% on average. These improvements are very significant since they occur in the areas where most of the system's congestion was observed.

The impact of changing the current number of nurses available in the hospital was evaluated. This sensitivity analysis compared the number of patients waiting in the different zones for treatment versus the change on the total number of nurses available. The level of nurse's availability is expressed on percentages which go from 40% to 160% of the current system. Figure 4 shows the graph for this analysis.

It was observed that changing the total number of nurses did not impact significantly the number of patients waiting in the red and yellow area queue. This could be solved by modifying the policy for admittance. For example, the hospital could consider stopping admitting patients and sending them to alternative facility once the system has reached a maximum number of patients in the system. That will result on a constant number of patients in queue for the red and yellow zones. Otherwise, by changing the number of nurses in the system without modifying the admittance policy will allow more patients to be admitted and treated, but the queue length will remain unchanged.

Various alternatives for the discharge policy from triage were considered using different scenarios comparison through Rockwell Software Process analyzer. The discharge policies evaluated were the discard of arriving patients when the number of patients in the system is larger than 200, 300, and 400.

Table 4: Number of patients waiting in queue and the percentage change using OptQuest.

	Number of patients in queue for nurses using OptQuest		Improvement from the starting system	
	avg	max	avg	max
Green zone	0	4	<1%	43%
Yellow zone	145	152	4%	24%
Red zone	66.68	140	37%	7%
Black zone	0	0	<1%	<1%

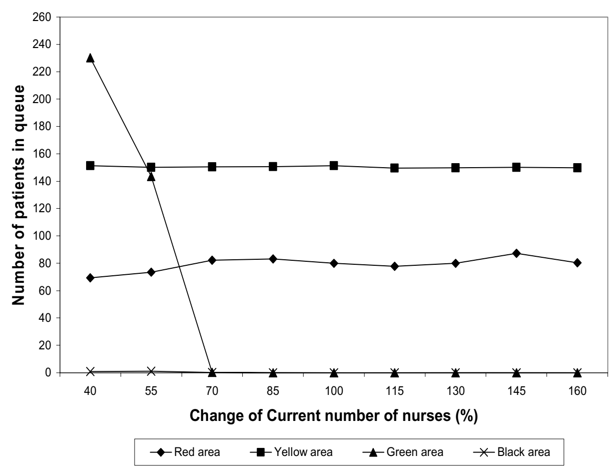

Figure 4. Sensitivity analysis on the impact of changing the proportion of nurse

8 CONCLUSIONS

Arena Simulation software was used to model the dynamics of an emergency department during a pandemic influenza scenario to determine an improved policy for the allocation of nurses in the five different zones (red, yellow, green, black and triage). OptQuest for Arena was used to propose a new allocation of the nurses to decrease the number of patients waiting in the queue. Significant results were observed in the decrease of queue length for the yellow and red zone which are the most critical and congested areas in the system.

Through the comparison of different nurse availability versus the impact on queue length in the yellow and red zone, it was observed that the result were independent. That is, queue length did not depend on the number of nurses, but on better allocation policies.

9 FUTURE RESEARCH

Research on the area of allocation of resources can be expanded to other critical areas of the hospital such as physicians, vaccines, antivirals, beds, and ventilators. These resources are also very critical for the operation of the hospital during pick patient demand scenarios.

Hospital managers make very complex decisions. In cases of mass casualty where uncertainty is present and previous experience is limited, the process of decision-making turns even more complex. Thus, it is essential to use computer support systems to evaluate policies, and the potential impact on the hospital performance. These policies include: when to discharge a patient?; and How often treatment should be delivered?

The scope can also be expanded to other institutions that are affected by the emergence of pandemic influenza virus such as transportation systems, schools and airports.

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