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SIMULATION OPTIMIZATION FOR EMERGENCY DEPARTMENT RESOURCES ALLOCATION

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ABSTRACT

The objective of this paper is to find out an optimal allocation of resources in emergency department (ED) via system simulation to smoothen the flow of ED. The construction of model that based on actual situation can demonstrate the waiting time and system time of patients in ED. Then, study the model and apply compatible with National Emergency Department Overcrowding Scale (NEDOCS) and OptQuest in Simul8 to increase the performance in ED and management of treated patients and thus increase the degree of satisfactions of patients. The results analysis shows that the overall performance in ED can be increased by 8% by new human resources allocation studied.

1 INTRODUCTION

An Emergency Department (ED) is a department which needs to face uncertainty everyday; the ED should have sufficient resources to overcome unexpected injuries and diseases. The ED is also a place that provides nonstop emergency treatment throughout the year, so the public can have proper treatment whenever they suffer accidents. (Chen 2000) While the quality of the ED service is an important issue, the quality is also indicated by the waiting time of patients, treatment given, emotions of the doctor, nurse management of patients, etc. Overcrowding and high flow in ED will have higher probability of conflict occurrence. (Wang et al. 1999) Conflict happens in every ED, so enough crews and resources are needed to confront the crowded situation in order to maintain the quality of ED. (Chen 2004)

According to statistical analysis of the Department of Health, Taiwan, the growing rate of emergency patients in year 2005 to year 2008 is 4.43%, while the statistics analysis of the U.S. Centers for Disease Control shows that the amount of emergency patients increased from 90,000,000 to 110,000,000 in a ten-year time of 1992-2002. Obviously, an increasing number of patients treated is the common trend in the world (Zhan 2003). Besides, the aging population in Taiwan also increases the amount of emergency patients. Due to data analyzed, aged patient was one quarter of total emergency patients; adults were at about 30%. The treating time for an aged patient is evenly higher than a young. The average treating time for a young patient (18-64 years old) is 5.0 hours, while 9.5 hours for an elderly patient (more than 75 years old). (Chi 2009) The data indicates that reducing the treating time effectively can increase the quality of the whole ED.

This paper investigated the impact of modeling the key resources, doctors, nurses and sickbeds. The ED patients in this case were distributed into four triage levels, and the cycle treating time for different levels of patients are distinct. Then, we propose a new scenario of resources allocation due to different level of patients, doctors, nurses, sickbeds and the resources needed by those emergency patients. A proper allocation of medical crew within the whole medical system could make the efficiency of limited resources to the highest. (Chen 2006) Robertson & Hassan (2001) point out that a sufficient amount of medical crew is directly proportional to the quality of treatment. Shortage of human resources would lead to blood infections, the increase of rate of patients hospitalized and death. (Fridkin 1996) Khare (2009) mentioned that lack of sickbeds would delay the treatment of an emergency patient. McMillan (1986) referred that when the patient comes to the emergency department, regardless of which triage level is assigned, the patient and their family will feel anxious and pressing, wish to receive treatment immediately; if this expectation can not be achieved, unsatisfaction occurs and the quality of treatment is affected.

2 PROPOSED METHODOLOGY

In this study, our aim is to improve the flow of the ED by increasing the quality of treatment in ED. Waiting time, cycle time, emotion of doctors, management of doctors, and etc, indicates the quality. The following methods were used in this study.

2.1 System Simulation

Saunders et al. (1989) said the system simulation is an infinite potential tool to plan how to allocate the resources without changing the actual resources in the system. Kelton (1999) defined system simulation as a process to simulate the actual system by computer technology. Simulation can also be what the outputs may produce due to different allocations made under different conditions and to study the outputs to make a reference for improvement. Since the processes in an ED are very complicated, high costs would be incurred if every new resource allocation takes an actual test; so, system simulation is used. Due to the changing of number of doctors, nurses, sickbeds, and other variables, the waiting time, system time, and efficiency of the human resources can be obtained and then analyzed.

The Opt Quest function in Simul8 is a Tabu search which is a macro-type heuristic algorithm for solving combinatorial optimization problems and not in the traditional local search escape local optimal solution using their own mechanism (Local Optimum) to achieve the best Solution (Global Optimum). It needs to generate a starting solution, according to a neighborhood of the initial solution generated by other nearby neighborhoods to find the best solution among the search of the initial solution as the next starting solution, and then generate a new neighborhood, and repeated until it reaches the stop searching criteria.

2.2 National ED Overcrowding Study (NEDOCS)

The crowdedness in the ED is being qualified over a few years, and NEDOCS and EDWIN (Emergency Department Work Index) are indicators to measure the crowdedness. NEDOCS is more commonly used by the medical industry. (Weiss 2004) NEDOCS is now used to measure the congestion in ED, using waiting time, amount of sickbeds, number of hospitalized patients, number of emergency patients and other parameters to analyze the factors via a regression equation. The greater the value of this equation the greater the degree of congestion.

3 MODEL DESCRIPTION

This study is based on the situation at a medical center in Taiwan. The hospital currently employs approximately 2721 crews; there are 625 physicians (which includes 285 attending physicians), 1500 sickbeds, 95,262 hospitalized patients annually, 1,517,745 outpatients annually, and 63,843 emergency patients annually. Thus, by analysis, there are 5320 times of emergency patients.

This research applied system simulation to achieve an “actual: status of ED. The input parameters of this simulation are shown in the following:

The distribution of patient arrival time

1. The proportion of patient triage level
2. The frequency of inspection of patients

3. Allocation of diagnosis time
4. The time required for each diagnosis
5. Allocation of human resources

The outputs of the model are focus on:

1. The average waiting time of patients
2. The average time of patients in ED
3. The rate of utilization of human resource
4. The rate of sickbeds occupied
5. NEDOCS value.

The key indicator NEDOCS was developed for the U.S. medical industry mainly used to measure the degree of congestion of ED. The index formula is as follows:

$$\mathbf{NEDOCS} = \left(\frac{\mathbf{P_{bed}}}{\mathbf{B_t}}\right) \times 85.8 + \left(\frac{\mathbf{P_{admit}}}{\mathbf{B_h}}\right) \times 600 + \mathbf{W_{time}} \times 5.64 + \mathbf{A_{time}} \times 0.93 + \mathbf{R_h} \times 13.4 - 20$$

In which, P_{bed} is the total number of patients in ED at time t, B_t is the total number of sickbed in ED at time t, P_{admit} is the total number of patients waiting in hospital at time t, W_{time} is the time of patients in the emergency room waiting for empty sickbed, A_{time} is the longest time of emergency patients waiting to be hospitalized and R_n is the number of emergency patients which use inhale apparatus.

A NEDOCS score $\geq$ 100 means that the ED is in crowding state; the higher the score, the higher the congestion level. A NEDOCS score <100 means ED is below the congestion level. In this study, we use NEDOCS as an indicator to measure the strength of emergency resources allocation.

3.1 Model Constructing

In this case, the emergency treatment procedures are shown in the following:

- Clinical Room (CR): The first area that all patients arrive to register and triage. Patients will triage at this area to diagnosis the injury level and decide the sequence for treatment. According to the data, there is one nurse in charge in triage for every shift (night shift, noon shift, day shift). The patient will be directly sent to the ED if his triage level is diagnosed as first level (most emergency level); other triage levels (Grater than and equal to 2) will be sent to MED. The arrival rate of patients (EXP; minutes): day shift: 13.11; noon shift: 9.27; night shift: 11.45. The operating time of patients after triage obey Triangular (0.2, 2.05, 7) (units: minutes). The percentage of each triage level: 1st level: 11%, 2nd level: 59%, 3rd level: 27%, 4th level: 2%, 5th level: 1%

- Main Emergency Department (MED)：

  Triage level of 2 or more than 2, and patients from CR will receive treatment in ascending order, which means triage level of 2 receive treatment first, level of 3 the next and so on. There are three physicians and three nurses in this department, and each patient need one sickbeds, the diagnose time obey Triangular (8, 16, 24) (units: minutes) while the requirement for further tests depends on the diagnosis (Tables 1 and 2). The tests includes: blood test, urine test, MRI test, fluid examination, etc. After diagnosis, the patients will be informed to follow different treatment management: leaving the clinic, further observation in observing unit, sent to intensive care unit (ICU), or sent to normal ward. In Table 3, it shows the proportion of managements for different level patients.

Table 1: The proportion of Tests of Every Triage Level Patients

No.	1st level	3rd level	4th level	5th level
1	15.48%	20.53%	21.46%	45.38%
2	39.89%	42.71%	49.77%	35.71%
3	23.27%	20.09%	11.67%	16.81%
4	11.42%	9.75%	9.33%	2.1%
5	6.42%	4.32%	4.67%	0%
6	3.52%	2.6%	3.1%	0%
Total	100%	100%	100%	100%

Table 2 The Cycle Time of Tests of Every Triage Level Patients

No.	Time (minutes)
1	EXP (3.4)
2	EXP (107.4)
3	EXP (55.6)
4	EXP (75.3)
5	EXP (49.8)
6	EXP (49.8)

Table 3 The proportion of managements for different level patients.

Management	2nd level	3rd level	4th level	5th level
Observing unit	55.87%	43.6%	42%	32.69%
Hospitalized	2.65%	3.01%	3.33%	0%
Leave	41.48%	53.39%	54.67%	67.31%
Total	100%	100%	100%	100%

- Resuscitation Room (RR): Patients with triage level of 1 from CR will receive treatment in RR. This area consist of 8 sickbeds, and every patient needs to be treated on sickbeds. Seriously injured patients will be sent to the operating room (OR); the operating time is Uniform (30, 50) (units: minutes). The ratio of patients needing an operation is 4.73:95.27. The processes in this department follow First In First Out (FIFO). Two physicians and two nurses are in charged in this area, while the data analysis cycle time and disposal is not discussed due to limited space.
- Observing unit (OU): The flow of patients in this unit follow FIFO, and the two procedures treating and examining are repeating. Physicians will make an inspection patrol every 8 hours, and the time needed for patrolling is corresponding to the amount of patients, with each patient requiring 5 minutes. The maximum observation time is 48 hours; after that, patients will be informed the next treatment management. The proportion of different treatment management is not discussed herein due to limited space.

The allocation of resources are distributed as follows:

- Distribution of physicians: Assume that the abilities of every physicians are the same.
- Distribution of nurses: Assume that the abilities of every nurse are the same. Allocate 1 nurse in triage area, 3 in MED, 2 in RR and 3 in OU.
- Distribution of sickbeds: In this case, there exists a total of 60 sickbeds in ED, in which 52 are for emergency treatment and 8 are for first aid. If the amount of sickbeds available is zero, substitute wheelchairs as sickbeds. In this study, we assume that enough sickbeds are provided and patients cannot be hospitalized if sickbeds are insufficient.

4 RESULTS AND ANALYSIS

Using Simul8, we calculated the NEDOCS value every 2 hours, and 12 NEDOCS values are obtained for one day. The trends of NEDOCS value showed that 83% of EDs are overcrowded. At the peak hours (4 to 10 in the afternoon), the level of congestion indicated critical overcrowding. Thus, only 17% of the day is not crowded and the average NEDOCS value is 126.79.

Model testing: Apply Simul8 to test whether the model suits the actual situation. Assume that H_0: the lag times for model system and actual situation are the same; H_1: the lag times for model system and actual system are not the same, and the level of significance α=0.05. According to the obtained t-value and p-value, this model is believed to have sufficient ability to reflect the actual situation.

Optimal Improvement: Apply compatible the installed function in Simul8 and OptQuest function to find a best combination of resource allocation as follows: Min Z=f(x), s.t:, =n, x_1,x_2,x_3,x_4,x_5,x_6 In which the x_1 represents the number of MED physicians, x_2 represents the number of RR physicians, x_3 represents the number of OU physicians, x_4 represents the number of MED nurses, x_5 represents the number of RR nurses, x_6 represents the number of OU nurses, m represents the total amount of physicians in MED, RR, OU and n as the total amount of nurses in ED, RR, OU.

Use NEDOCS value as the reference of improvement, the ratio of physicians and nurses as lists: MED(3,3), RR(2,2), OU(3,3) as the initial solution. The limit factor is total amount of physicians and nurses are 8. After the experimentation, the optimal solution obtained as shown in Table 4.

Table 4: Results of QptQuest

Case	**Physicians**			**Nurses**			**NEDOCS**
	MED	RR	OU	MED	RR	OU	
Initial Solution	3	2	3	3	2	3	126.79
Optimal Solution	4	2	2	3	2	3	116.63

Table 4 shows that shifting of 1 physician from OU to MED can reduce the NEDOCS value from 126.79 to 116.63, which represents an 8% improvement. Figure 1 shows the differences between the allocation of human resource of initial solution and the optimal solution. The most significant difference is within the duration 10:00-22:00. (Blue line represents the initial solution, while red represents the optimal NEDOCS value.)

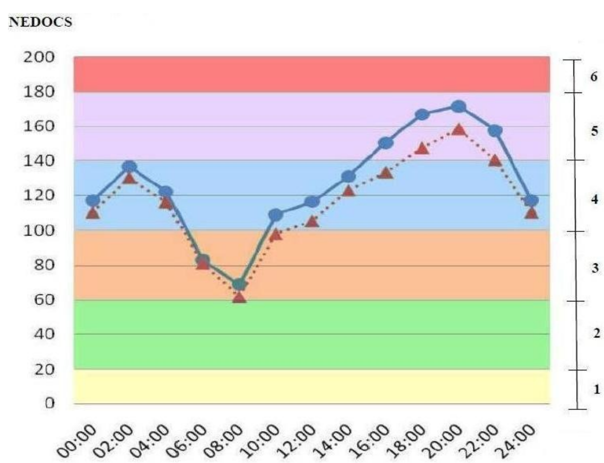

Figure 1: The Allocation of human resources in ED

In this study, we try to allocate 9 people as optimal allocation. The results obtained are shown in Table 5. It shows that shifting of 1 physician from OU to MED can reduce the NEDOCS value from 97.63 to 88.73, which represents 9% of improvement. The results from allocating 7 people are shown in Table 6

Table 5: Results of OptQuest (9 people)

Case	Physicians			Nurses			NEDOCS
	MED	RR	OU	MED	RR	OU	
Initial solution	3	3	3	3	3	3	97.63
Optimal solution	4	3	2	4	2	3	88.73

Table 6: Results of OptQuest (7 people)

Case	Physicians			Nurses			NEDOCS
	MED	RR	OU	MED	RR	OU	
Initial solution	2	3	2	2	3	2	7547.44
Optimal solution	2	2	3	2	2	3	987.69

5 LIMITATION

In this research, we assumed that:

1. The qualifications, efficiency for every crews are equal
2. Patients follow the queuing rules, arranged according to severity of disease and no unexpected events
3. Departments are all independent operation
4. Patients will not leave, even with long waiting times.
5. ED stays in stable situation and won't be affected by any other external factor
6. Volunteers, interns and other uncertainties are not included in the study
7. No problem on staff scheduling

6 CONCLUSION

In this study, our target is to improve the quality, flow in ED and the management of patients; we applied Simul8 to simulate the situation with 8 and 9 people in ED, and analyzed the results. The results showed that the allocation of human resources had obvious influence on the NEDOCS value and the degree of crowdedness with 8 people. Besides, we obtained a solution by Simulation Optimization, which is simpler in the actual situation. In the actual case, there are other factors which will affect the results; for example, the abilities of crews, interns having less experience than employed physicians, and other factors. The results of this study can be presented as a reference to the hospital management and the ED. In the future, this study can be enhanced by using more controlled variables to present a more reliable reference.

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