Resource Analysis in Emergency Department Using Simulation-based Framework

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Abstract

The critical objective of the operation in Emergency Department is to provide the fastest response to all patients needed with the proper treatment until they stabilized. The emergency department at Thammasat University Hospital in Pathumthani, Thailand, the patient flow was analyzed and re-engineered to achieve efficient services. This paper proposed a decision support tool and method for analyzing the staff scheduling by using the integrated simulation model in order to increase patient safety and reduce patient waiting time. Organizing appropriate human resource such as emergency department physicians, nurses and other related resources are required in order to reduce the patient waiting time in the ED subject to some constraints such as the budget restrictions and KPI of waiting time.

Keywords: Emergency Department, Simulation, Waiting Time Reduction

1. INTRODUCION

In Thailand, there are public hospitals, private hospitals and clinics. Most of them are public hospitals where many patients choose to be treated there because of the medical expenses are cheaper than those private hospitals. However, resources such as physicians and nurses are not adequate enough to serve all patients in one time. So, scheduling plays the important role in managing resources by schedule the right staff to the right task in the right time. It is difficult to find the optimal solution for scheduling in the real world because it is dynamic and can be changed all the time. Improper staff scheduling lead to inefficient task performance which lead to patient waiting time increase, patient satisfaction decrease, and overall performance decrease and so on. Simulation model is an appropriate method to simulate the ED operation system in order to analyze performance of related resources in every process and indicate the bottleneck process and then lead to final solution to improve the flow.

Thammasat University Hospital is one of an interesting emergency department of public hospital which has the potential treatment and service. "Accident and Emergency Information System"(Figure 1) has been used for recording patient information and operation time in every process. This is the main source that has been used for data collection. The patients who arrived at ED are divided in to 2 main types which are Trauma and Non-Trauma patient and subcategorized into 5 levels as followings: Resuscitated, Emergent, Urgent, Non-urgent, and Other level depending on patient’s condition. This paper aims to improve operation performance such as decrease service time, total cost, and optimize resources to treat patients effectively. By using the simulation techniques, it shows the bottleneck process that slow the patient flow. Then, various scenarios will be simulates to observe the improvement of the process and compared to find the best solution for increasing services time and quality.

2. PROPOSED INTERGRATED FRAMEWORK

2.1 Literature review

Igor Georgievskiy and Zhanna Georgievskaya (2008) proposed the flowchart model of the patient flow in the emergency department to evaluate the impacts of different proposed operating strategies on the waiting times and throughput rates for patients in the ED. Medeiros, D. J., Eric Swenson, and Christopher DeFlitch (2008), observed some performances of the flowchart design in emergency department and arrival rate to design the table of arrival process. Ahmed, Mohamed A., and Talal M. Alkhamis., Georgievskaya (2009) also constructed processes of the patient flow to observe, the waiting time and the service time and find the optimal schedule of the resources. Waleed Abo-Hamad, Amr Arisha (2011) acknowledged simulation-based decision support framework is presented in healthcare process improvement.

Furthermore, there is improving performance has grown significantly and also plus the application of optimization application for operational decision support are become increasingly primary under A.K. Athula

Wijewickrama and Soemon Takakuwa (2006), which have focused on simulation analysis of an outpatient department of internal medicine in a university hospital. This is the new way to reduce costs and improve efficiency in outpatient services. Wan Jie and Li Li (2008) considered the simulation for constrained optimization of inventory system by using Arena and OptQuest which is presented comparing the different outcome by determining a mathematical programming. Besides, Shao-Jen Weng, Lee-Min Wang, and etc. also mentioned to find out an optimal allocation of resources in emergency department via system simulation to smoothen the flow of ED by constructing of model based on actual situation.

2.2 An Interactive Simulation-based Decision Support Framework

An overview of the framework is given in Figure 1 where a detailed description of each component is provided through the next sections, which has three procedures to interrelate decision maker.

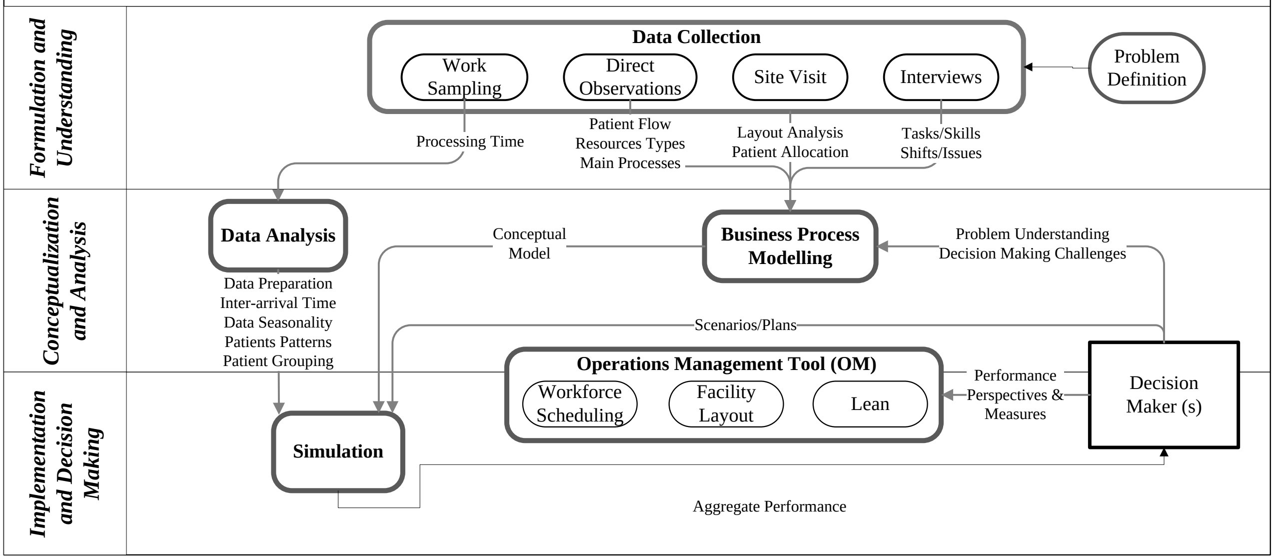

Figure 1: An interactive simulation-based decision support framework

In Figure 1, an interactive simulation-based decision support framework is used as a tool to understand Srinagarind emergency department process in order to identify the problem. Once, problems are clearly notified, the appropriate solution is designed and applied to solve exiting problems. An interactive simulation-based decision support framework has three phases as following;

2.2.1 Formulation and Understanding

In the formation and understanding phase, relevant data is collected by several methods. This phase focuses on gathering relevant information for each process in ED. Most of quantitative data is gathered from site visiting, interview and direct observation and work sampling. Example of data collected are processing time of each stage in ED, type and amount of patient in each time period, waiting time in each stage, etc. Site visiting is selected to be done to observe the real system in order to validate with the model. Experts and related staff in ED are interviewed about the system such as physicians, nurses, administrators and chief of ED. Once gathering all information needed, we will see the big picture of process and be able to define the problem.

2.2.2 Conceptualizations and Analysis

All data and information gathering from phase 1 is combined and analyze in this phase. In this phase, data is analyzed and identified. So, the problem in ED is clearly defined. Then, conceptualized model is designed and developed. The flow is created by identifying the entities that flow in the system such as patient, medical staff. Each process will be described about data and resources to be used in this stage. The conceptual model is created in order to be a guideline model for simulation model. After conceptual model is completed, it is important to validate with the medical staff in ED for correcting the process and model validation.

2.2.3 Implementation and Decision Making

After conceptual model is validated, the model is translated to the simulation model. All relevant data is assigned in each process. During creating simulation model, the model is verified and validated by ED medical staff to ensure the corrected processes. Once the validation and verification are completed, the simulation model is run and generated result. The result is interpreted and verified by ED medical staff to finalize and validate. Once the simulation result is similar to real system, the alternative scenarios are evaluated. The better solution is provided to ED medical staff for making decision whether to implement better simulation scenario to the real system or not.

2.3 Emergency department – a case study

Regarding the process of ED in TU hospital which its entire process consists of the several major areas can be divided into 4 sections as follows: triage area, lab tests area, examined area, and administration area. The staff schedule is divided into three shifts per day; 12 am-8 pm, 8 pm-4 pm, and 4 pm-12 am, respectively. There are five nurses for the first shift and then eight nurses for the rest in each shift.

The patients arrive the ED at the triage area. Arriving of the patients can be divided into 2 types; car (walk-in) and ambulance. According to arrival of car, the arrival rate is amount one people per 15 minutes or 96 patients per day. Another one, arrival by ambulance, the rate is one people per 480 minutes or 3 patients per day. The detailed arrival rate distributed throughout a day is shown in Figure 2. Patients who arrive by car or walk-in are needed to register at the administration area with an administration staff and wait in the triage area to be triaged. There is one administration staff in the first two shifts and two staffs for the third shift. All patients who arrive by ambulance are needed to take the pre-triaged process by nurses who classify patients into 4 types as followings: Critical(2%), Emergent Emergent(18%), Urgent(21%), and Non-urgent(59%), depending on patients' condition. A patient will be treated by physician. Then, if the patient needs lab test such as, X-ray, CT Scan (Computed Tomography Scan), MRI (Magnetic Resonance Imaging), Stool Exam, etc., which are performed by technicians. There are three types of technicians; Urine Test technician, Stool Exam and Blood Test technician, MRI Test technician and X-ray technician. There are three technicians in each shift per day for the Urine Test, Stool Exam and Blood Test. There is one technician in each test of each shift per day for the MRI Test technician and X-ray technician. The patient will take the first lab test and to wait for the lab result in the emergency department and transfer to a physician for diagnosing. The amounts of physicians in each shift are two, three, and four physicians, respectively.

3. MODEL DEVELOPMENT

3.1 Emergency Department Layout

The department has officially many areas following classified patient; critical, emergent, urgent and non-urgent, which are from pre-triage area. Besides, the ED has an ambulatory car area with a capacity of trolley spaces which are reserved directly to the critical area and emergent area, and other cases will stay in the rest area. From entrance of ED, there are areas followed by case of patients: critical area, emergent area, and urgent area. For non-urgent patient will separated to OPD (Outpatient Department) outside ED. The first two areas are at the left-handed side and the rest is on the right-handed side. By nurse station, the information center of patient is in a middle of ED layout for available transferring patient data. Before diagnose, the document of patient will transfer to physician in the diagnostic room and then patient will go to lab test methods. There are 4 distinct areas of lab test in the ED: urine test and stool exam room, blood test room, MRI room and X-ray room. In addition, there are two small operation room for critical and emergency case.

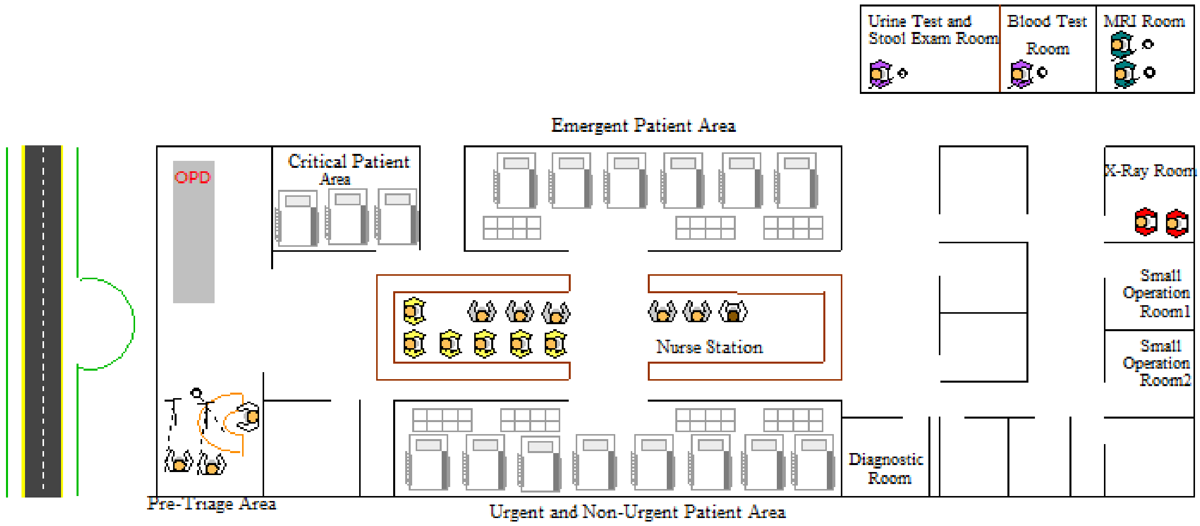

Figure 2: ED physical layout and main areas including ED staffs

3.2 ED Staff

Since a 24-hour department, the ED has separated into 3 shifts; 12 am-8am, 8am-4pm, and 4pm-12pm. All staffs are divided by considering patient flows, so the numbers of medical staffs most work on the period, from 4 pm- 12 am.

Table 1: Number of Medical Staffs

Resources	Number of Medical Staffs				Total
	Shift			OPD Shift	
	12am-8am	8am-4pm	4pm-12pm	4pm-12am	
Administration Staff	1	1	2	-	4
Nurse	5	8	8	3	24
Physician	2	4	5	4	15
Technician	3	3	3	-	9
Nurse Assistance	3	6	6	-	15
Medical Specialist	1	3	4	-	8
X-ray test Technician	1	1	1	-	3
MRI test Technician	1	1	1	-	3

3.3 Key Performance Indicators Selection

According to the Key Performance Indicators (KPIs), ED in Thailand has identified the selection of quality to show efficient ED performance which has two main key performance areas: patient throughput and ED efficiency. For the first key for measuring performances of patient throughput are the average waiting time and average ED time, whereas for ED efficiency there are; resource and layout efficiency. Figure 3 illustrates the decomposition of key performance indicators (KPIs) according to the ED Thailand approved.

Table 2: Key Performance Indicators for the ED

		KPI	
		Minutes	Target (%)
Waiting time	Resuscitated	4	100
	Emergent	15	90
	Urgent	30	90

3.4 ED Process Mapping

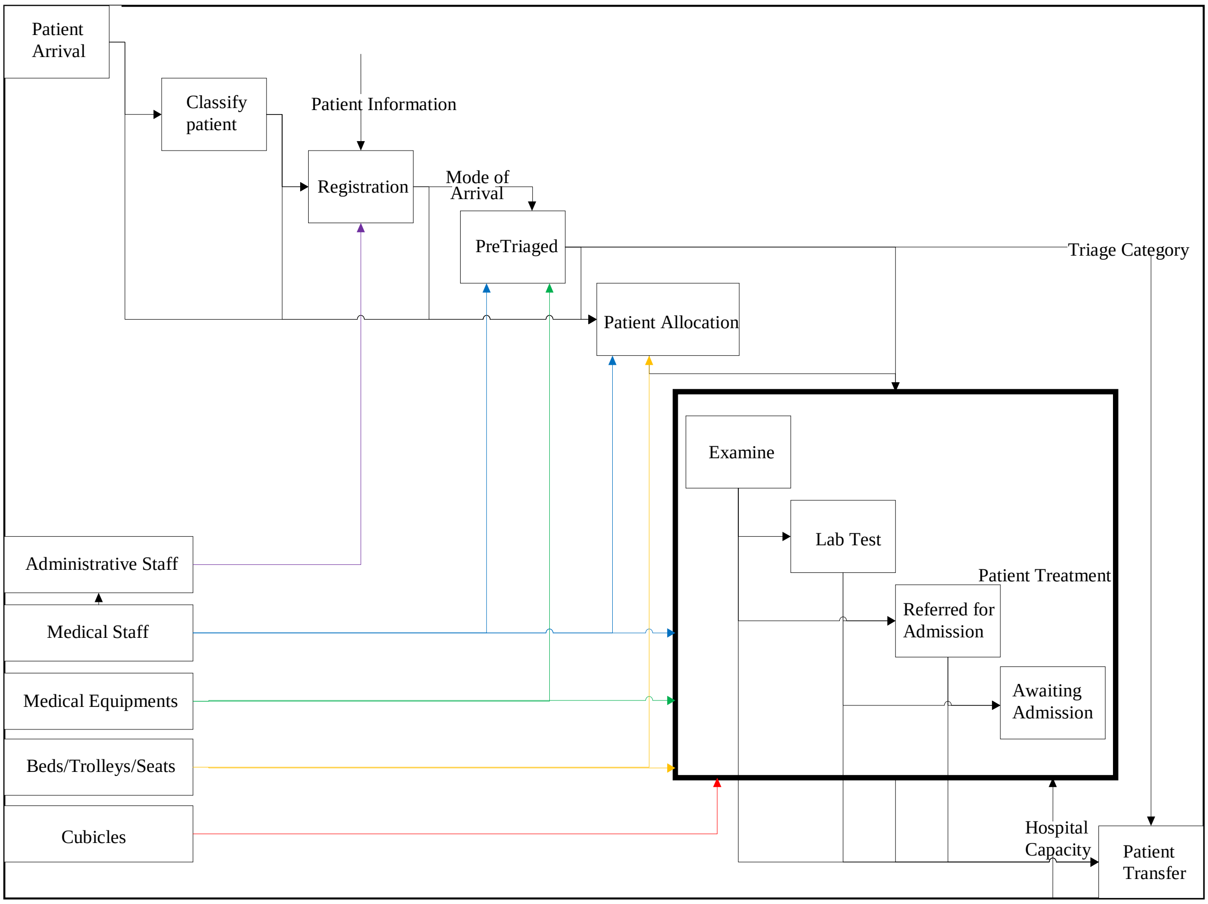

Figure 3: Process mapping of main ED process using IDEF0

Based on the analysis of patient flow through the ED, a detailed flowchart is built which highlights the common processes and decision points involved in the care of patients through the ED. Each ED process is then broken down into smaller sub-functions with key resources at each medical stage are identified and detailed by using IDEF0, which is a powerful tool for modeling complex systems which allows users (e.g. ED staff, decision makers, system analysts) to comprehensively understand the system through modeling decisions, actions, and processes in a hierarchical form. The main unit of an IDEF0 model is an activity block that describes the main function of the process. ICOMs (Input, Control, Output and Mechanisms) are represented by horizontal and vertical arrows. Process control (top arrow) can from patient information (e.g. arrival time, triage category, and presenting complaint)which facilitate the activity (e.g. ED physicians, nurses, and physical beds/trolleys).

The utilization of IDEF0 for process modeling has not only improved the quality of simulation models but also it enhanced the communication levels among decision makers and the staff (e.g., doctors and nurses) through modeling the underlined work flow, decision points, and processes in a hierarchical form. This hierarchical structure kept the model scope within the boundaries represented by breaking down processes into smaller sub-functions.

3.5 Patient Flow Analysis

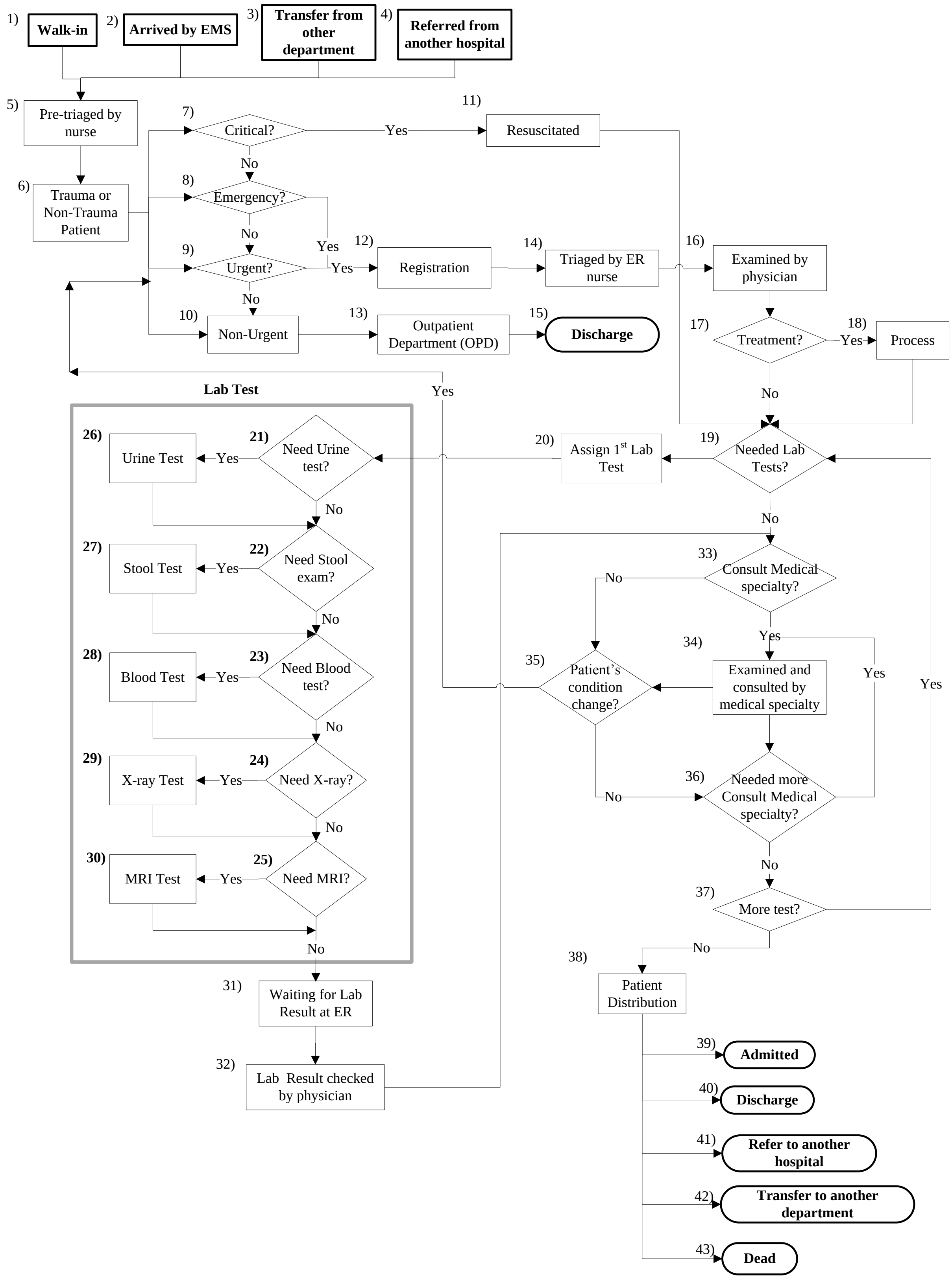

Figure 4: High-Level Process View of the Emergency Department

The following step, the physicians will decide if the patients are required to see the medical specialist for the additional consult. If the patient gets the consult from medical specialist, the patient is needed to wait in the emergency department until the specialist is available. Following this, the medical specialist will decide that the patient should have more lab tests or not. The available numbers of medical specialist in each shift per day are one, three, and four specialists, respectively. The next step depends on the medical specialist's decision which will make the permission for the patient to be admitted in the hospital, or transfers to other hospital, or discharge, or transfers to other departments by nurse assistants. There are three nurse assistants in the first shift and six assistants for the rest of each shift.

3.6 Empirical Data Analysis

All of the processes are depicted in Figure 4. The detailed number of each medical staffs is summarized in Table 1.

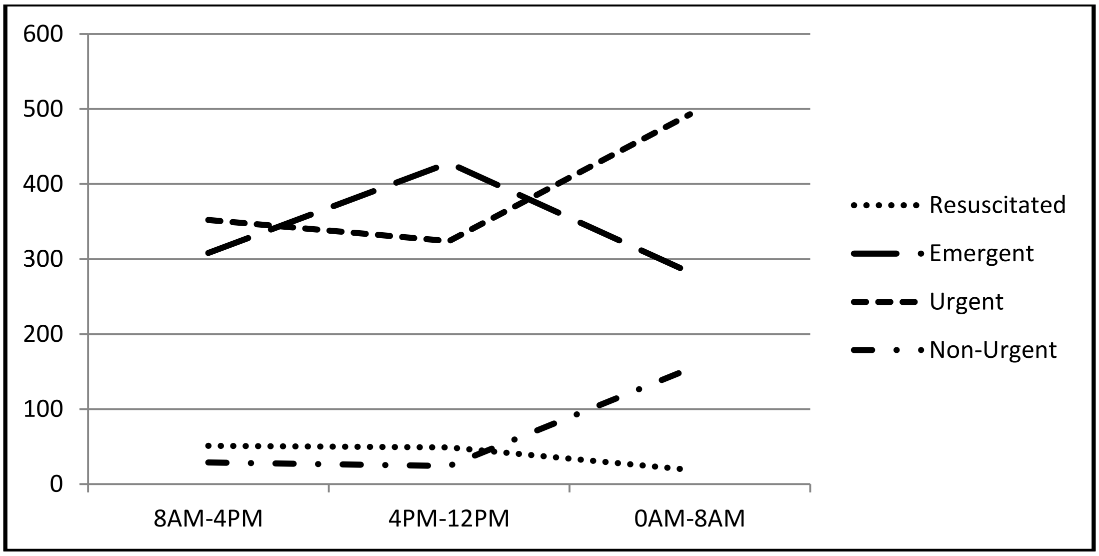

Figure 5: Plot of The estimate arrival rate of patients per hour for each period

Table 3: Analysis of patient allocation within the emergency department

Patient Level	Arrival Rate (%)
Resuscitated	2.12
Emergent	18.15
Urgent	20.84
Non-Urgent	58.89

4. SIMULATION MODEL DEVELOPMENT AND VALIDATION

4.1 Model Construction

The comprehensive data are collected at the Emergency Department of Thammasat University Hospital by interviewing the medical staffs, observing the process, and intensive data collection. They have provided the estimated arrival rate, the estimated service time distribution in each stage of the process and estimated waiting time in each process. It is suitable to use the poison distribution for the arrival process based on its property. In addition, the service time in each process provided by nurse is estimated by using the Triangular distribution which is shown in Table 4.

Table 4: Service time distribution in each stage of the process

Process Number	Service time distribution in each stage		
	Process	Type of Resource	Delay Type (minutes)
5	Pre-Triaged - Emergency case - Urgent case	Nurse	Triangular (1,3,5) Triangular (1,5,9)
11	Resuscitated	All resources	Triangular (60,270,480)
12	Registration	Administration staff	Triangular(1,5,9)
13	OPD	Physicians, Nurses	Triangular (10,40,480)
14	Triaged	Nurse	Triangular(2,11,20)
16	Examination - Emergency case - Urgent case	Physician	Triangular (1,4,7) Triangular (1,7,44)
18	Treatment	Nurse	Triangular (1,7,42)
20	Lab Test - MRI - X-Ray - Blood Test - Stool Test - Urine Test	Technician	Triangular (4,9,14) Triangular (4,7,10) Triangular (2,3,4) Triangular (5,7.5,10) Triangular (5,7.5,10)
32	Check Lab Result	Physician	Triangular (2,3.5,5)
34	Examined	Medical Specialist	Triangular (1,2,7)
38	Patient distribution	Nurse Assistant	Triangular (30,135,240)

4.2 Verification and Validation

In this study, we construct our simulation model using ARENA software from Rockwell Inc. where the working time starts from 12 am to 12 pm (24 hours) and runs 2 replications with the distribution in each process, specified from the previous section. The model is validated by comparing the output of the base scenario shown in Table 5 against the actual number of patient waiting and queue time in each process. From the results, waiting time in each process of the model and the observed time in the same process are almost identical. Therefore, our estimated distributions of arrival rate and process delay time are closed to the actual data.

Table 5: Waiting time in simulation

Process Number	Process	Actual Waiting Time	
		Average	Maximum
5	Pre-Triaged - Emergency case - Urgent case	0.94 1.19	22.69 31.45
11	Resuscitated	0.28	2.41
12	Registration	1.03	10.31
13	OPD	160.05	408.50
14	Triaged	0	0.01
16	Examination - Emergency case - Urgent case	4.67 13.30	175.34 193.25
18	Treatment	0	0
34	Examined	0.51	21.42
38	Patient distribution	85.24	340.78

6. EXPERIMENTATION AND SCENARIO ANALYSIS

6.1 Scenario Design

In our study, we propose to use the maximum waiting time in the ED as the Key Performance Indicators (KPIs) and for scenarios comparison. To minimize the maximum waiting time, we propose to adjust the process of seeing physicians in each case reasonably by increasing the amount of physicians at the process with higher queue time in maximum value than KPIs. First, we need to identify the maximum waiting time in each case. Therefore, the maximum waiting time for emergent and urgent should be minimized to 15 and 30 or less by focusing resource number of physician.

Table 6: Number of Medical Staffs for Scenario Analysis

Resource	Base Scenario			Total	Scenario 1			Total	Scenario 2			Total
	12am -8am	8am-4pm	4pm-12pm		12am -8am	8am-4pm	4pm-12pm		12am-8am	8am-4pm	4pm-12pm	
Administration Staff	1	1	2	*4*	1	1	2	*4*	1	1	2	*4*
Nurse	5	8	8	*21*	5	8	8	*21*	5	8	8	*21*
Physician	**2**	**4**	**5**	***11***	**3**	**4**	**5**	***12***	**4**	**4**	**5**	***13***
Technician	3	3	3	*9*	3	3	3	*9*	3	3	3	*9*
Nurse Assistance	3	6	6	*15*	3	6	6	*15*	3	6	6	*15*
Medical Specialist	1	3	4	*8*	1	3	4	*8*	1	3	4	*8*
X-ray test Technician	1	1	1	*3*	1	1	1	*3*	1	1	1	*3*
MRI test Technician	1	1	1	*3*	1	1	1	*3*	1	1	1	*3*

Table 7 shows the waiting time in each process after adjusting the number of medical staff. By scenario1, we added one physician at 12am - 8am (Table 6). Although the maximum waiting time for both cases are reducing, but they do not still meet the KPIs target. Then, we added one more physician at the same shift. The results shows that the maximum waiting time for the case of emergent is meet the KPIs and the case of urgent is close to the KPIs too.

Table 7: Waiting time in each process

Process Number	Process	Waiting Time					
		Base Scenario		Scenario 1		Scenario 2	
		Average	Maximum	Average	Maximum	Average	Maximum
5	Pre-Triaged - Emergency case - Urgent case	 0.94 1.19	 22.69 31.45	 2.46 2.32	 18.09 20.62	 0.92 0.46	 11.06 8.75
11	Resuscitated	0.28	2.41	0	0	0	0
12	Registration	1.03	10.31	2.84	39.75	1.47	16.87
13	OPD	160.05	408.50	155.15	446.82	153.69	422.08
14	Triaged	0	0.01	0.04	3.49	0.03	4.69
16	Examination - Emergency case - Urgent case	 4.67 13.30	 **175.34** **193.25**	 0.65 2.56	 **28.53** **54.97**	 0.23 0.70	 **15.46** **33.15**
18	Treatment	0	0	0.09	5.89	0	0
34	Examined	0.51	21.42	0.78	51.33	0.05	3.94
38	Patient distribution	85.24	340.78	140.63	360.57	117.21	300.71

6.2 Result Analysis

Table 8 shows the improvement from the current staff distribution of Scenario 1 is 14.6% improving for the maximum average of waiting time but negative 2.38% improvement for the maximum average number of patients and negative 1.85% for the maximum average of total time. By the current staff distribution of Scenario 2 is all improving at 32.28%, 3.49%, and 8.81% for the maximum average of waiting time, the maximum average number of patients and the maximum average of total time, respectively.

Table 8: The Scenario Comparison

	Comparing Scenario			**Improvement (%)**	
	Base Scenario	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Maximum Average waiting time	109.65	93.64	74.25	**14.6**	**32.28**
Maximum Average Number of patients	86	84	89	**-2.38**	**3.49**
Maximum Average Total Time	554.73	565.18	505.85	**-1.85**	**8.81**

According to the Process Analyzer Chart (Figure 6), the comparing results which are interesting in the hospital management to optimize the staffing subject to minimize the queue time for patient dismiss per unit time for reducing the total time. As the result, the maximum average of total time of Scenario2 is lower than the current scenario and Scenario1. Hence, it is the optimal scheduling.

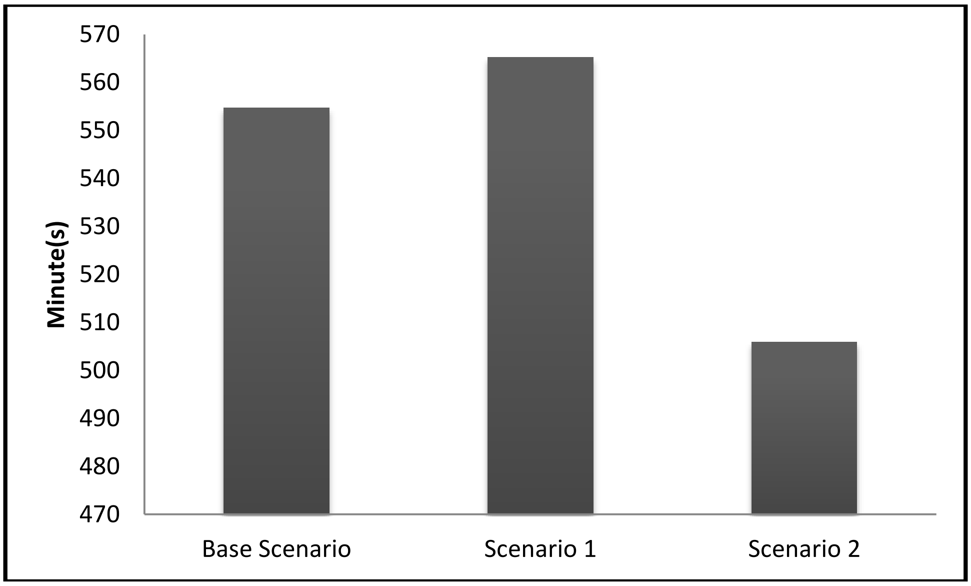

Figure 6: Comparison of the Maximum Average of Total Time

7. DISCUSSION

The high-level process view of emergency department has been well-received by ED staffs, especially nurses, and acknowledged as a sustainable tool to support their strategies. First of all, the development of process view prior to the development of the simulation model has greatly helped in the collection of the relevant information on the operation of the system (i.e. data collection) and, therefore, reduced the effort and time consumed to develop the simulation model. The utilization of IDEF for process modeling has not only improved quality of the simulation model but it also enhanced the communication levels among decision makers and the staff (e.g., physicians and nurses) through modeling the underlined work flow, decision points, and processes in a top-to-bottom from. Regarding to the structure, it kept the model scope within the boundaries represented by breaking down process into smaller sub-functions. Such the organizational strategy allowed the system to be easily refined into more details until the model is as descriptive as necessary for the decision maker. Furthermore, the total time, adding the resource number of physician, as focusing in emergent and urgent case, can decrease the total time – process and waiting time – in a practical way of the simulation model.

CONCLUSION

While demand of patient serving medical care in the emergency department goes up, the resource of medical staffs are less than the increasing of medical taker. As a result, patients have to wait in the ED process by case considering of pre-triaged nurse. Hence, we analyzed the patient flow in the emergency department at Thammasat University Hospital in Thailand and performed the comparison of the various numbers of physicians in order to minimize the total time of the patient. We propose 2 scenarios to compare with the base scenario in order to reduce waiting time in ED. The results show that increasing physician in emergent and urgent case reducing patient waiting time. The maximum average waiting time of the scenario1 is improved 15% and scenario 2 is improved 32% by comparing to the base scenario. From the comparison, scenario 2 is recommended because the maximum of total time is smaller than scenario 1.

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