Simulation Model for Emergency Department

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Abstract

The paper presents a comprehensive research study of the simulation model developed for a hospital Emergency Department. The study was conducted in the Emergency Department (ED) at The Ohio State medical Center. A detailed patient flow process chart is developed to study time delays, patient medical processes, resources, material flows in the system. A simulation model was developed using Arena (7.0) to model the process flow of patients in order to analyze the ED System performance. The response variable in our study is patient throughput. Lean Management based strategies were proposed for improving patient throughput in Emergency Department. The lean management strategies focus on creating value in system, reducing non value added times, reduction of queues and chaos in system. A statistical hypothesis testing experiment was conducted to study the significance/ non significance of proposed strategies for implementation in Emergency Department.

Key Words: *Emergency Department, Simulation, Work Flow, Lead Time.*

Introduction

The Emergency Department (ED) at Ohio State Medical Center specializes in the treatment of critically ill and seriously injured patients and possess a comprehensive array of the most up to date diagnostic and treatment services coupled with a highly trained and experienced health care staff. It was observed that the overall time patients spent in the Emergency Department of the hospital was significantly higher (500 minutes) than the benchmarked time for the patient length of stay (LOS). This has an adverse impact on patient throughput in the ED. If the patient length of stay in the ED is high, then the waiting times for new incoming patients in the ED is high and the in-process patient volumes who have received partial medical service in the ED is also high. These factors contribute to a significant decline in the ED system performance.

The objective of our research study was to analyze and evaluate ED system performance. The research study was conducted in several phases. The first phase involved construction of a detailed flow chart of the "As Is" ED system. This enabled us to understand the work flow of patients, physicians and nurses in the ED system. The second phase involved construction of a detailed simulation model using Arena (7.0). The simulation model calculates the performance evaluation measures such as total patient length of stay, total patient throughput, waiting times in the system, resource utilization, etc. The simulated values are compared with the benchmarked values and the values observed when the work sampling studies were conducted. The simulation model helped us to understand the ED system dynamics and was an invaluable tool for evaluating the variations in the performance measures.

We propose Lean methodologies to optimize the performance of the Emergency Department. The lean management based methodologies were embedded in the simulation model in to obtain the ED system performance measures. The simulated measures of performance were tabulated and a statistical Design Of Experiments (Analysis of Variance) was performed in order to obtain significant and non- significant factors in the study.

Literature Review

Samaha and Armel (2003) present a simulation model and a complete analysis of operations in the Emergency Department of Cooper University Hospital, which is a 554-bed licensed facility. Miller and Ferrin (2003) simulated a large hospital in South East USA and proposed six sigma-based process improvement ideas for reduction of patient length of stay.. Garcia et al. (1995) analyzed the flow of patients at the Mercy Hospital with the objective being to minimize the waiting times of patients. The above papers describe a simulation model of the Emergency Department but do not describe adequate policies and recommendations to improve the performance of the Emergency Department. A thorough statistical analysis is not conducted to identify significant and non- significant factors impacting the ED performance.

Centeno et al. (2003) observed in their study at the Baptist Health South Florida that one of the significant operating costs in the Emergency rooms is the staffing costs. Baesler et al. (2003) have developed a simulation model for calculating the maximum possible demand increment in an Emergency room of a private hospital in Chile. The simulation model was used to create a curve that analyzes and predicts the patient length of stay in the system. Baesler et al.,(2003) performed a statistical Design of Experiments analysis which considered 4 factors: # of physicians, # of paramedics, # of receptionists and nature of emergency room. The above papers describe the simulation model to measure the operating costs in the ED but fail to suggest the operations process improvement measures. The Analysis of Variance results of the analysis explains the significant factors but the factors are not incorporated in the simulation model to study the improved response measures.

Bard et al. (2005) discuss the problems, hospital management faces several times in a day as the demand for health care services departs from the planned schedule. Harrison et al. (2005) present a stochastic version for the Harrison Millard multi- stage model of the flow of patients through a hospital division in order to model correctly not only the average but also the variability in occupancy levels. Bard and Purnomo (2005) present two models to solve the midterm preference scheduling problem based on shift view formulation. The above papers describe a linear integer programming formulation to optimally solve the staff planning problem in the hospital. The math-based models are however able to optimally compute solutions to small size problems and fail to solve large size problems especially when the hospital staff size is large. The linear models fail to capture non linear constraints especially in lieu of staffing preferences and random variations in staff schedule.

Akcali et al. (2006) present a network flow approach to optimizing hospital bed capacity decisions. Their approach ignores the random variations in patient demand and variations in patient processing times in the hospital. The utilization levels of the hospital staff is not taken into account while calculating bed turnover rate. Basu Ghosh and Cruz George (2006) present a Physician Requirements Planning model in response to high demands for physicians in hospitals. The Physician Requirement Planning model is an artificial intelligence based software system used for calculating the number of physicians and physician rosters based on the physician schedules. The software system is essentially restricted to physician planning but does not capture the ED operations planning and management aspects. The software takes into account the physician planning problem in a disjoint fashion but fails to capture the complexities of Emergency Department system.

Kevin Leonard (2004) studied the role of patients in designing health information systems and the case of applying simulation techniques to design a patient record interface. Baker (2002) studied the sensitivity analysis for health care models using statistical methods. Their research determined which parts of the model caused greatest uncertainty in the predictive models and is a decision support tool for the modeler, helping them to refine the model further or collect additional data. Beguin and Simar (2004) analyze expenses linked to hospital stays and a methodology to calculate outliers.

Jones et al. (2002) describe a forecasting model that forecasts the daily number of occupied beds due to Emergency Admissions in the hospital. They discovered that the number of occupied beds is related to Emergency Admissions. Utley et al. (2003) address the question of what level of capacity is required to operate a system if cancellations of booked patients are kept to a low level. Karnon et al. (1998) discuss the suitability of modeling techniques for economic evaluations of health care programs in general. These approaches do not accurately capture the uncertainty in patient volumes and the ability of hospital resources to respond efficiently to the fluctuations in the patient volumes.

Rohleder et al. (2007) report on the use of simulation modeling for redesigning phlebotomy and specimen collection centers at a medical diagnostic laboratory. The objective of their research was to reduce average waiting times and their variability. The simulation model does not incorporate the graphical and animation features as would be available with Arena. The waiting times calculations have not been accurately explained in the paper.

Channouf et al. (2007) develop and evaluate time series models of call volume to Emergency Medical Service in a Canadian city. Denton et al.(2007) worked on the problem of sequencing and scheduling surgeries under uncertainty. The scheduling model does not obtain optimal solutions in a polynomial amount of time.

Eitel and Rudkin (2010) suggested a methodology for improving service quality by understanding Emergency Department flow. The methods proposed were statistical forecasting, discrete event simulation modeling Michael Kamali and Schneider (2013) surveyed low acuity patients to understand the patient preferences and expectations. Agostine (2013) discusses the decision making under uncertainty in health care environment and suggests the appropriate simulation model based framework for probabilistic decision making. Hamid Reza Feili (2013) discuss a simulation optimization approach and a queuing theory approach to reducing waiting of patients. Lucia Cassateri (2013) discuss the discrete event simulation models for modeling and analysis of health care systems. Rust (2013) discusses the application of Lean & Agile Approaches to dynamic analysis of health care services.

Problem Definition

The problem considered in this paper is the performance analysis and operations improvement of Emergency Department. The response variable in the study is patient throughput. We analyzed the current state of the Emergency Department at OSU-MedCtr and constructed a Flow Process Chart of the system. The Flow Process Chart is explained by Figure 1 and Figure 2. The process that was charted is presented in two phases: Phase 1 describes patient medical process till the lab operations are performed and Phase 2 is from the point of patient lab operations to patient disposition from ED to the hospital floor or home. The problem in this research study focuses on maximization of patient throughput. Maximization of patient throughput can be achieved by minimizing patient lead time, minimizing work in process, reduction of chaos in the system

Patient throughput in the paper is defined as the number of patients served by the hospital in defined time horizon i.e., one day. Patient length of stay is defined as time spent by the patient in hospital system from the point patient reaches the hospital door to the point when patient leaves the Emergency Department system. Resources in the Emergency Department are doctors, nurses, specialty consultants, patient beds etc. Auxiliary resources which are required by the Emergency Department but which may be present in other areas of hospital are Lab, X Ray, CT, MRI Scan etc. Improvement in resource utilization of hospital resources is an important element of hospital process and operations procedures. The emergency department consists of a set of nurses supervised by a charge nurse. A nurse attends to more than one patients. The nurse: patient ratio is fixed for acute care and fast track patients. There are a few specialty consultants allocated to the Emergency Department depending on commonly observed ailments. There is a physician dedicated to Emergency Department and a few physicians who perform duties in Emergency Department as well other hospital areas such as

Intensive care units. The bottleneck resource identification in our study would include calculating the resource which requires maximum processing time/ workload. The resources required for patient care such as injections, needles are arranged in a central nursing station. The number of beds in the Emergency Department is kept fixed.

The data for our experiments collected is the primary data which has been collected after conducting time and motion studies in the Emergency Department on different days of the week and in different weeks. The probability distribution for the data points is plotted from standard commercial software Matlab/Arena. After the primary data collection is conducted on different days and a distribution is fitted with aid of the software, the interval of the distributions are fed into the simulation model and the model is run for one day. The research studies focus on measurement of performance measures such as patient throughput, resource utilization, patient lead time with the aid of a simulation model. The research study also includes development of lean management based strategies for maximization of patient throughput. Lean management based strategies attempt to create value in system by reduction of different types of waste such as motion, resource, inventory, time, transportation, money, underutilized human potential, overprocessing, etc. The 5S methodology of sorting, straightening, shine, standardize and sustainance has also been incorporated in development of lean management-based strategies.

Emergency Department Analysis

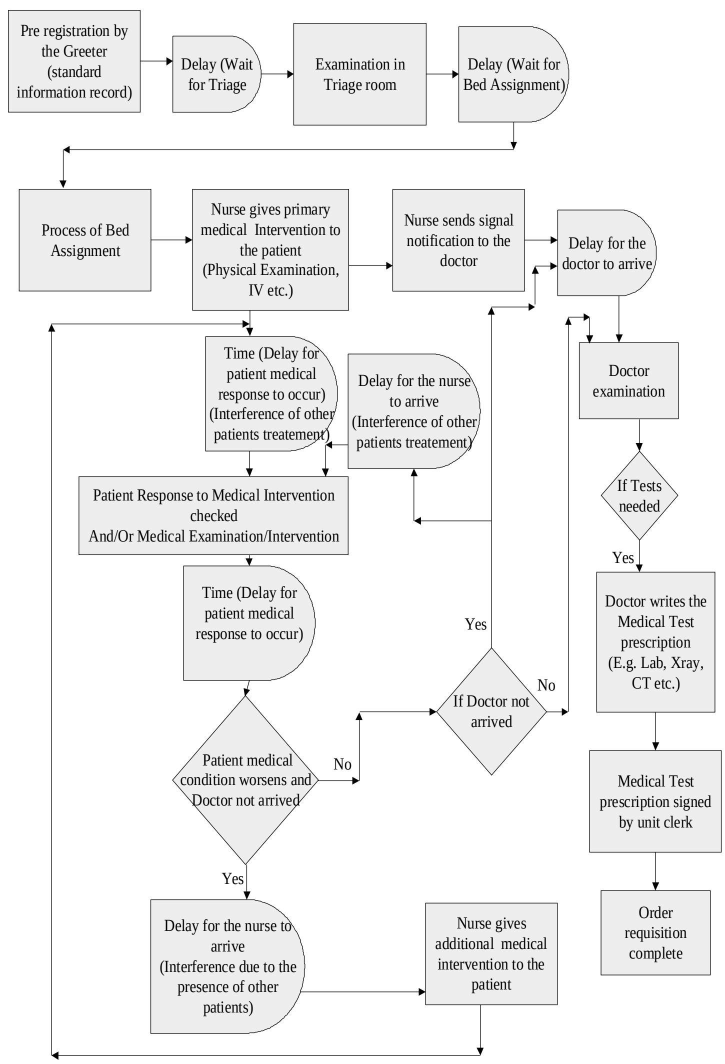


Figure 1 : Emergency Department Phase 1

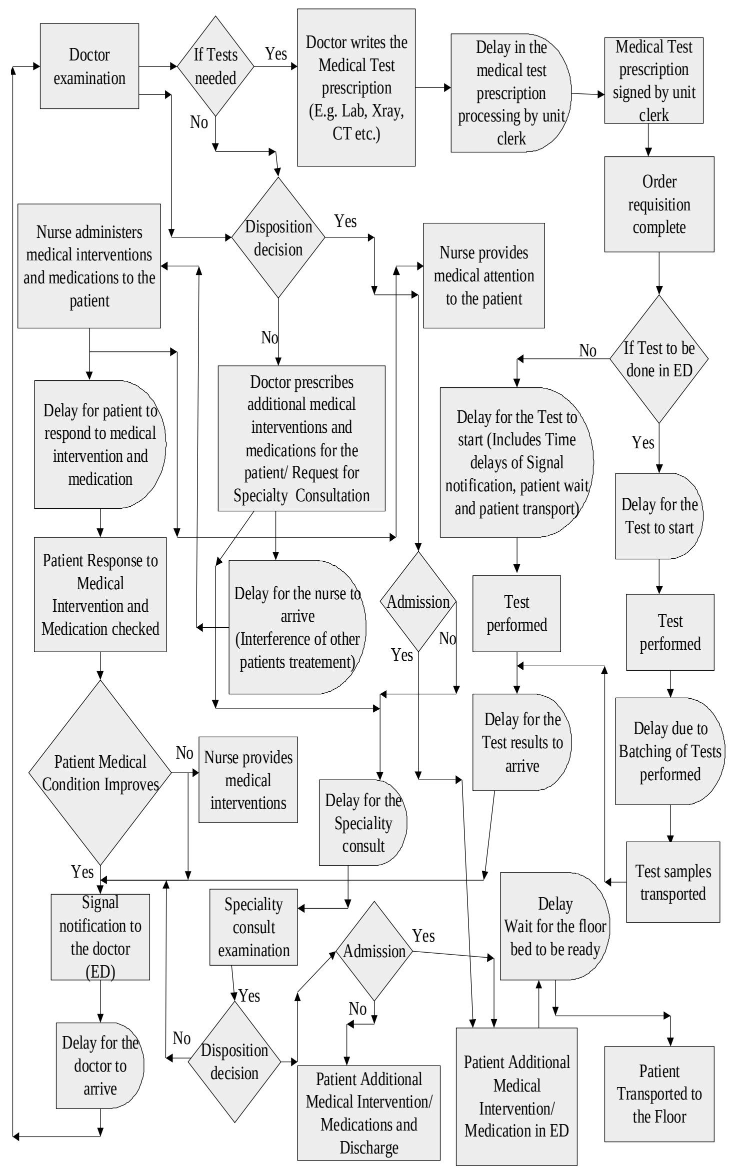


Figure 2 : Emergency Department Phase 2

The process starts with the arrival of the patient at the entrance of the Emergency Department and subsequent patient preregistration, checking of vital signs, and patient triage. The patient triage can be defined as the first aid treatment given to the patient at the onset in the Emergency Department. The processes in the ED system vary depending on the medical condition of the patient. Medical treatment in the Emergency Department involves medical examination by ED physicians, medical examination by specialty consultants, interventions provided by nurses and medications. The number of physicians and specialty consultant visits is dependent on nature of the medical condition of the patient. While waiting (i.e., time delay) for the patient to respond in some cases, the next medical intervention is delayed until the arrival of specialty consultants for medical examination. The medical treatment of the patients also involves administration of tests such as lab, X rays, CT, MRI, etc. On average it was observed that the number of doctor (ED physician visits) per patient varied from 3 to 4. While medications provided require a Physician order, other interventions may or may not require the physician. The nurse: patient ratio for acute care currently in the system was observed to be 1: 3 while that for the fast track was observed to be 1:7. However it was observed that the ratio changes due to varying staff availability and staffing capacity as well as high variability in the patient demand. The changes to the nurse: patient ratio was initiated by the charge nurse.

In our research study we propose a variable "patient lead time" (also defined as length of stay). The motivation behind introducing this factor was that patients with high acuity may have high or low patient lead time whereas patient with low acuity may have high or low patient lead time. Thus we have four different cases, depending on patient high and low acuity levels and patient high and low lead times. It was observed that the nurse: patient ratio was different for all possible scenarios depending on patient's acuity level and cycle time in the system. The expected patient lead time at the onset would aid the charge nurse in optimizing the nurse: patient assignment by rapid dynamic updating of nurse: patient ratio. The rapid dynamic updating of nurse: patient ratio would ensure complete patient satisfaction and optimize the system performance measures.

It is noted that if the nurse: patient ratio is kept a constant for the entire duration of the day, high quality and high service level of patient care cannot be achieved. The patient demands fluctuate with a high degree of variation at different time intervals of the day and for different days of the week. Hence if the nurse: patient ratio is kept as constant, the nurse: patient assignment would not take into account the acuity levels of the incoming patients. This would lead to low service levels of patient care, patient dissatisfaction and increase in patient lead time. Hence the dynamic updating of nurse: patient ratio levels are carried by the charge nurse subject to high variability in patient volumes and acuity levels. In the OSU- MedCtr ED facility, a white board is deployed to record the patient IDs, nurse IDs and nurse: patient assignment. The white board is dynamically updated by the charge nurse to update the assignment ratios.

Patient disposition could either be patient floor admit or patient discharge. This disposition decision is made by an ED physician in consultation with the specialty consultant. The disposition decision in the current system is not taken preemptively by the physicians or the specialty consultants but is only taken in the later stages of the course of treatment in the Emergency Department. It was observed that in the case of patient admits to hospital floors, the examination by specialty consultants was observed to be frequent. The patient admissions on the floor were delayed on account of the floor beds not being ready for the admission of new patients. As a result it was observed that the patients had to stay in the Emergency Department for a significant amount of time although their medical treatment in the Emergency Department was complete. Hence this resulted in a significant amount of delay for admission of new arriving patients in the Emergency Department. This was a major concern from the point of view of criticality and acuity of patients and a loss of revenue to the hospital due to potential loss of patients. We performed time studies and collected data from the patient record sheets, pertinent to the above the flow chart in Figure 1 and

Figure 2. A simulation model was built in Arena 7.0. The three days were sampled from a month's period. We assumed that the patient arrivals are exponentially distributed with a mean of 8 minutes. Data collection for service times of medical process activities was conducted and distributions computed to calculate mean and standard deviations. We simulated the system for a period of one day. The one-day (1440 minutes) was the time for which the Arena Simulation model was run.

Simulation Model of Emergency Department

The input data for the simulation model was follows: The waiting times of the triage follow a uniform distribution between (3- 5 min). The average waiting times for the bed assignment follows a uniform distribution between (8 – 10 min). Since one nurse attends on average 3 to 4 patients at any given time, the average waiting times due to interference of other patients follows a uniform distribution from (5 – 7 min). The average waiting times for the doctor to arrive is 5 minutes for acute care and 15 minutes for fast track.

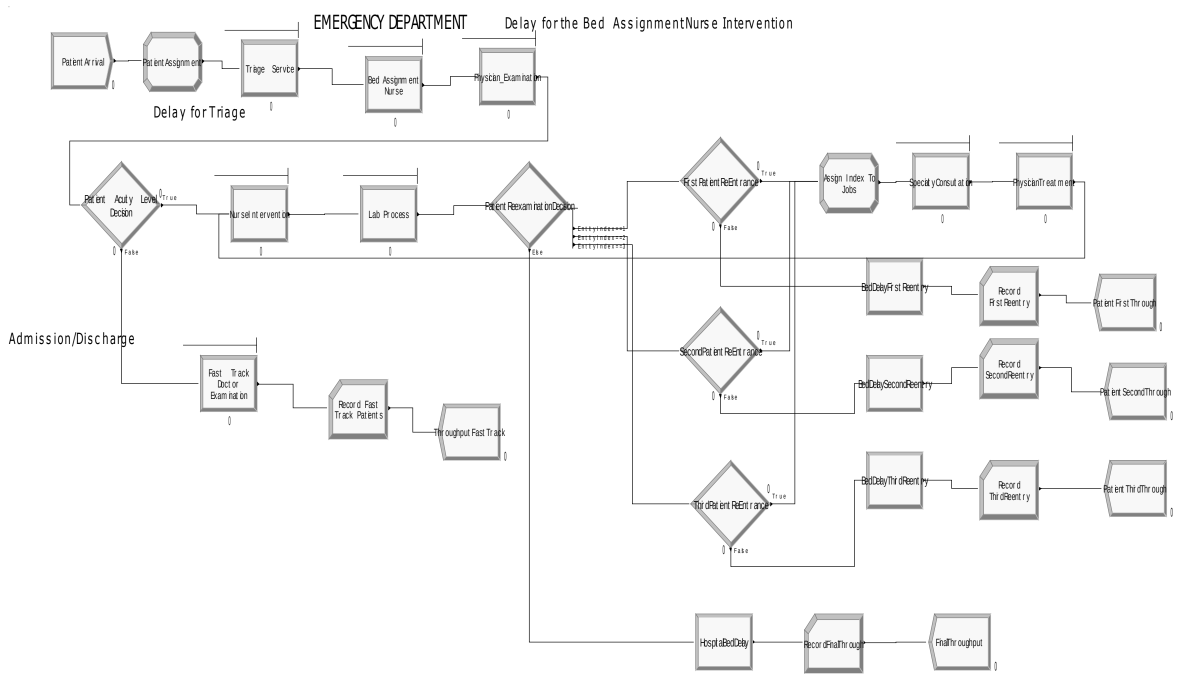


Figure 3 : Simulation Model

Figure 3 explains the Simulation Model of Patient Process Flow.

The Emergency Department staff has a tendency to batch test results and the average waiting times due to batching of test results is 15 min. Since Lab is a bottleneck resource in the Hospital and receives requests from all inpatient units, surgery department, ICU and the Emergency Department, the waiting times for the arrival of lab test results follows a uniform distribution from (20 – 25 min). The waiting times of the specialty consultant are on an average 10 minutes whereas the waiting times of the patients for getting to the hospital floor bed follows a uniform distribution from (30-35min). Throughput is defined as the number of patients served by the Emergency Room in a predetermined time horizon (set as 1 Day). Throughput includes fast track and acute care patients served in a time horizon.

Lean methodologies were developed for Emergency Department operations are listed below.

a) Implementation of Triage Short Form vs. Regular Form Triage

- The concept of Triage Short Form stemmed from the need to reduce the time taken for triage in order to increase patient throughput.

b) Implementation of Visual Display for Dynamic Nurse: Patient Ratio

- The concept of Visual Display stemmed from the need to reduce the time taken to do the nurse intervention, reduce the delay for wait for nurse and thus increase patient throughput.

c) Implementation of Preemptive Disposition Decision Making by ED Physician

- The concept of Preemptive Disposition Decision Making stemmed from the need to reduce the time taken by the ED Physician to attend to the patient and thus minimize the patient total lead time and increase patient throughput.

The above methodologies were also treated as Factors (Independent Variables) for the Design of Experiments. The Response Variables in the experiment were Total Patient Throughput in a day, Total Patient LOS for Fast Track Patients & Acute Care Patients Total Patient Length of Stay for Acute Care Patients. The Design of Experiments involves the implementation of the Paired comparison(t test) in order to evaluate the significance / non significance levels of the factors. Each Factor is tested at 2 levels: High Level (+) and Low Level (-). Triage Short Form Strategy involved perturbing the time taken to do the triage operation at high and low level (i.e., high and low times to perform triage operation). Visual Display for Nurse to Patient Operation involved perturbing time delay for conducting Nurse Intervention at high time values and low time values. Preemptive Disposition Decision Making Strategy involved perturbing time delay to conduct ED Physician examination at high and low time values. Sensitivity Analysis of the Simulation Model was carried out as follows: Each factor is embedded in the Simulation Model one at a time and the response variables are evaluated.

Statistical Hypothesis Testing

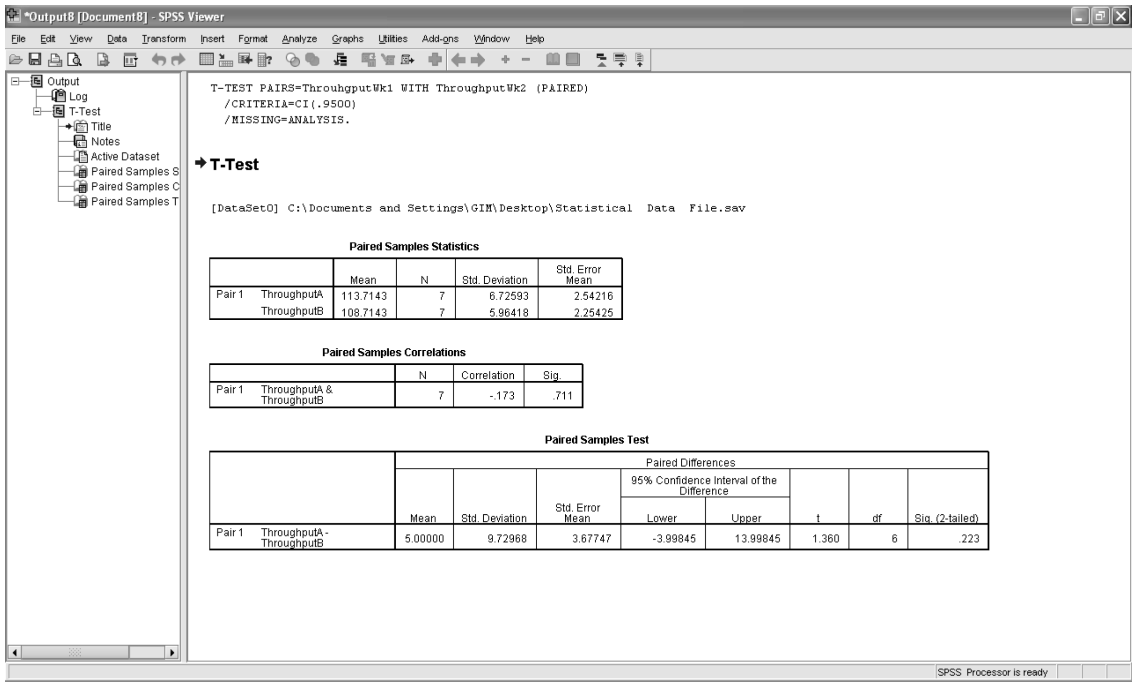
Response Variable : Patient Throughput

Independent Variables: Triage Levels, Nurse: Patient Levels, Doctor Staffing Levels For Decision Making

Before Implementation of Lean Strategy Implementation

Null Hypothesis : H0 : There is no significant change in throughput levels of Emergency Room in 2 weeks for which studies are conducted

Alternate Hypothesis H1 : There is a significant change in throughput levels of Emergency Room in 2 weeks for which studies is conducted.


*Output8 [Document8] - SPSS Viewer

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T-TEST PAIRS=ThrouhgputWk1 WITH ThroughputWk2 (PAIRED)
  /CRITERIA=CI(.9500)
  /MISSING=ANALYSIS.
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T-Test

[DataSet0] C:\Documents and Settings\GIM\Desktop\Statistical Data File.sav

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ThroughputA	113.7143	7	6.72593	2.54216
	ThroughputB	108.7143	7	5.96418	2.25425

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ThroughputA & ThroughputB	7	-.173	.711

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper			
Pair 1	ThroughputA - ThroughputB	5.00000	9.72968	3.67747	-3.99845	13.99845	1.360	6	.223

SPSS Processor is ready

Figure 4 : SPSS Screen Output

A paired sample Test and Screen Output from SPSS is displayed for 95 % Confidence Level

p Value = 0.223 p value > 0.05

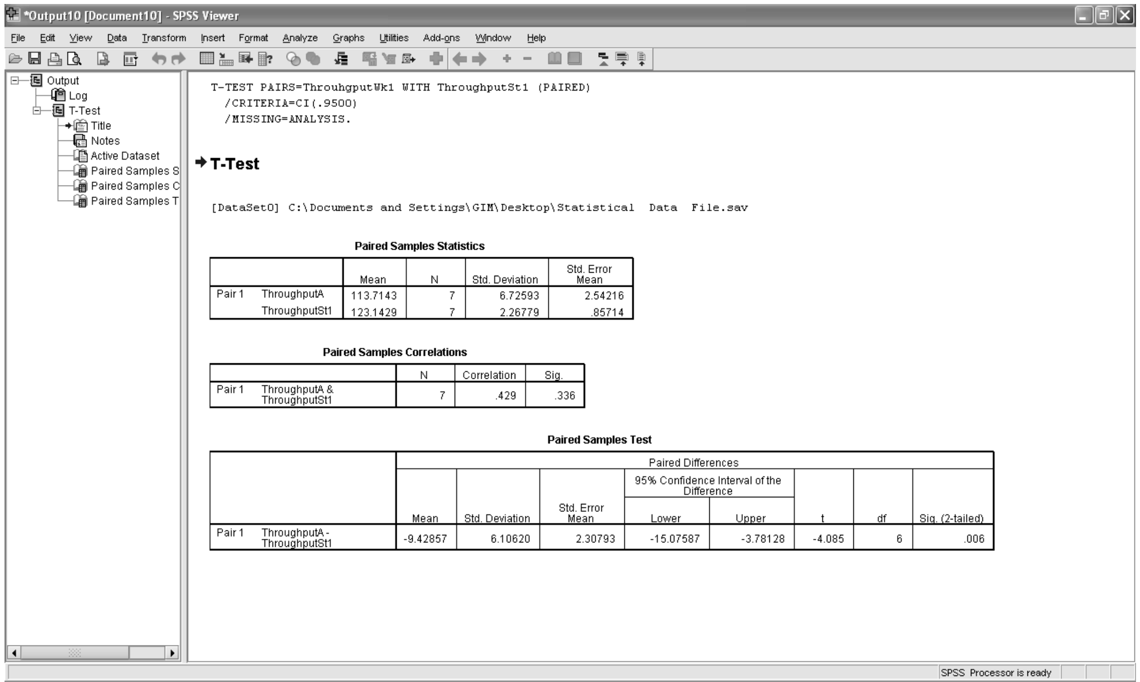
Null Hypothesis is accepted.

Conclusion : There is no significant change in throughput levels of two weeks in Emergency Room

SPSS Screen Out For Triage Short Form Implementation (95 % Confidence Level)

Null Hypothesis H0 : There is no significant change in Throughput Levels of Emergency Room before and after implementation of Triage Short Form Strategy

Alternate Hypothesis H1 : There is a significant change in Throughput Levels of Emergency Room before and after implementation of Triage Short Form.



*Output10 [Document10] - SPSS Viewer

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  /MISSING=ANALYSIS.
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T-Test

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Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ThroughputA	113.7143	7	6.72593	2.54216
	ThroughputSt1	123.1429	7	2.26779	.85714

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ThroughputA & ThroughputSt1	7	.429	.336

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	Upper			
Pair 1	ThroughputA - ThroughputSt1	-9.42857	6.10620	2.30793	-15.07587	-3.78128	-4.085	6	.006

Figure 5 : SPSS Screen Output

Since p value = 0.006 < 0.05 , Null Hypothesis is rejected

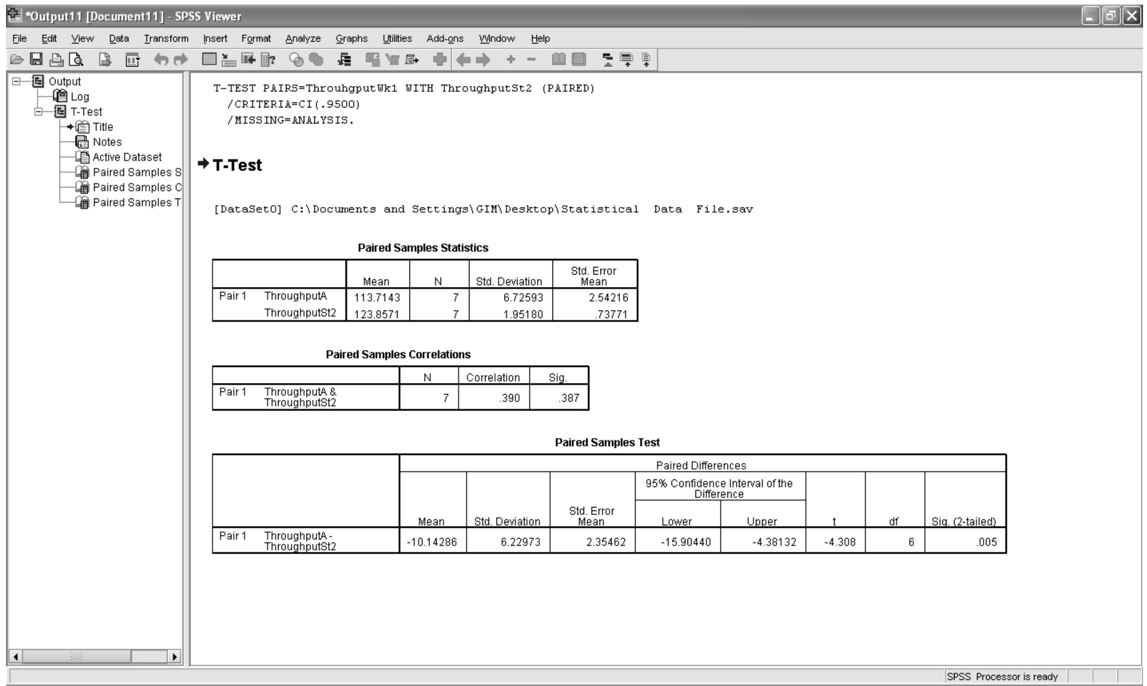
Conclusions : Implementation of Triage Short Form yields statistically significant change in throughput values of Emergency Room

SPSS Screen Out For Visual Display Implementation (95 % Confidence Level)

Null Hypothesis H0 : There is no significant change in Throughput Levels of Emergency Room before and after implementation of Visual Display Form Strategy

Alternate Hypothesis H1 : There is a significant change in Throughput Levels of Emergency Room before and after implementation of Visual Display Form

SPSS Screen Output (95 % Confidence Level Analysis)



Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ThroughputA	113.7143	7	6.72593	2.54216
	ThroughputSt2	123.8571	7	1.95180	.73771

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ThroughputA & ThroughputSt2	7	.390	.387

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	ThroughputA - ThroughputSt2	-10.14286	6.22973	2.35462	-15.90440	-4.38132	-4.308	6	.005

Figure 6 : SPSS Screen Output

p Value = 0.005 < 0.05 . Null Hypothesis is rejected

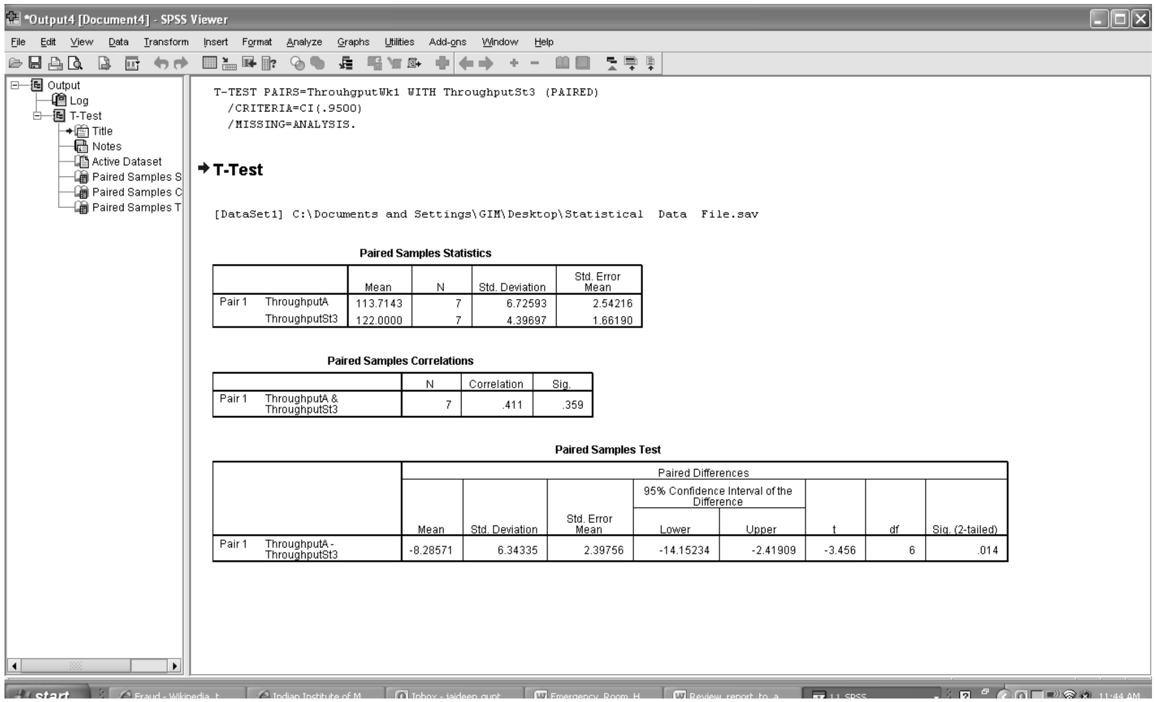
Conclusion: There is a significant change in through put levels of patients in Emergency Room due to the implementation of Visual Display strategy.

SPSS Screen Out For Visual Display Implementation (95 % Confidence Level)

Null Hypothesis H0 : There is no significant change in Throughput Levels of Emergency Room before and after implementation of Preemptive Doctor Decision Strategy

Alternate Hypothesis H1 : There is a significant change in Throughput Levels of Emergency Room before and after implementation of Preemptive Doctor Decision Strategy.

SPSS Screen Output (95 % Confidence Level Analysis)



*Output4 [Document4] - SPSS Viewer

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  /MISSING=ANALYSIS.
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T-Test

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Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ThroughputA	113.7143	7	6.72593	2.54216
	ThroughputSt3	122.0000	7	4.39697	1.66190

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ThroughputA & ThroughputSt3	7	.411	.359

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	ThroughputA - ThroughputSt3	-8.28571	6.34335	2.39756	-14.15234	-2.41909	-3.456	6	.014

p Value = 0.014 < 0.05 . Null Hypothesis is rejected

Conclusion: There is a significant change in through put levels of patients in Emergency Room due to the implementation of Preemptive Doctor Disposition Decision strategy.

Conclusions & Future Research

We analyzed the Emergency Department at The Ohio State University Medical Center. The workflow in the Emergency Department was modeled using the simulation. The simulation model considered the several system performance evaluation measures such as patient throughput, patient lead times, patient waiting times etc. which provide several insights in our analysis. We identified the independent variables (factors) based on Lean Thinking approaches which could potentially impact the ED system. The response variable of study was patient throughput. Next we conducted a paired t test to determine the statistical significance levels of the three strategies for implementation in Emergency room. The results of t test explain that before the lean strategies were implemented in the Emergency room, there was no statistically significant change in patient throughput levels observed. The t test results also explain that the implementation of lean strategies provides a statistically significant change in patient throughput values in Emergency room.

The conclusion of the research studies explains that implementation of lean strategies such as triage short form, preemptive doctor decision making by changing doctor staffing levels and visual display with a modified nurse:patient ratio can yield statistically significant change in patient throughput. Increase in patient throughput will yield to reduction in patient lead time, increase resource utilization and reduce chaos in emergency department.

Future work could involve development of network flow based approaches for analyzing an emergency room. A linear program could be developed for the network flow model to maximize the patient throughput.

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