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Applying the Seven Quality Control Tools to Improve Patient Experience in the Emergency Department

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Abstract

Patients visiting the emergency department (ED) experience a long waiting time until being admitted or discharged. Using the seven basic quality tools, this study investigates the reasons behind this phenomenon and provides suggestions for improvement. The analysis was conducted on data collected in the first half of February 2019. For that period, the complete data of 3020 patients out of 4062 patients were included.

The analysis showed that the average length of stay (LOS) is a little more than 2 hours and the percentage of patients of levels 3 and 4, of the Canadian Triage and Acuity Scale (CTAS), visiting the ED are 61% and 35% respectively. While more than 70% of the LOS period represents the time spent by a patient when initially seen by an ED physician until decision is made about his/her case, including lab and radiology procedures and further consultation(s) that seem to be necessary, around 18% of the LOS period is spent in triage, registration, and "waiting to be seen by an ED physician" related activities. The remaining 12% of the LOS period is spent in collecting prescribed medicines and/or arranging for admission or discharge. The analysis also showed that 10% of the patients have a LOS that exceeds 4 hours where most of them are CTAS3 and CTAS4 levels. As the ED is adopting the practice of referring patients with CTAS4 and CTAS5 levels to a 24-hour operating health center in the city, having CTAS4 and CTAS5 patients (37%) being seen by the ED physicians is a defect in following this practice. In order to improve various ED processes, it is recommended to add a doctor station at the triage area prior to registration, enhance human resource competencies through cross training on device utilization, enhance ED space utilization based on types of diagnosis, define customer/ staff interaction protocols, and revise procedures of admission, bed turnaround, and shift handover. The study also provided recommendations to enhance data collection and avoid missing some of patients' data.

Keywords: Seven basic quality tools, 7QC tools, Emergency department, Length of stay, The Canadian Triage and Acuity Scale, CTAS

I. INTRODUCTION

Improving patient experience is a recognized component of high-quality care at the public hospital where the study was conducted. The hospital provides health services to more than 1 million people, nearly half of the population of the city where the hospital is located, through the Emergency Department (ED). The hospital's board members are keen to realize how their patients are experiencing care so they can effectively translate their needs and preferences into higher quality, safer, and more efficient services. Streamlined processes and efficient services are critical factors of a satisfying patients' experience. In this study, the proper adoption of procedures that enhance the levels of these factors in the ED at the hospital under study is questioned as patients visiting the ED encounter a long waiting time until being admitted or discharged. The time spent by the patient (the patient's length of stay (LOS)) while visiting the ED is described as "Triage to Boarding Time", defined as the total time spent by patient at the ED from triage until boarding, and is composed of the following set of durations:

- **Door to Doctor:** the duration of activities related to triage, registration, and waiting areas from the time a patient arrives to triage until being seen by an ED physician.
- **Doctor to Decision:** the duration of activities related to bed, lab, and radiology areas where some of/all the following activities are performed:
  - Patient being examined by one of the physicians,
  - Making the electrocardiogram (ECG) procedure,
  - Running lab test(s),
  - Conducting radiology procedure(s),
  - Further consultations in complicated cases, and
  - Report writing by the ED physician and nurse.
- **Decision to Boarding:** the duration from report writing completion until patient's boarding including dispensing medicines by ED nurse through labeling and preparing the medication. The boarding order could be one of the following:
  - Discharge: patient's care has been completed,
  - Observe: patient needs further observation,
  - Admit: patient needs to be admitted,
  - Refer: referring patient to another healthcare provider (outpatient clinics, healthcare centers, or hospitals), or
  - Dead: patient passed away.

The scope of the study is to assess the level of performance of the ED against a set of key performance indicators (KPIs) determined by the Saudi Ministry of Health (MOH) ADAA Health program (ADAA) [1] using descriptive statistics and the basic seven quality tools.

II. RELATED WORK

In 1960s the Seven Quality Control Tools known as (7 QC tools) were first introduced by Ishikawa, one of the quality management gurus. His original seven tools were developed by introducing the flow chart or the run chart. Once developed, then new tools were developed for multiple reasons, but the basics of every related work is related to the 7 QC tools [2].

The 7 QC tools consist of graphical and statistical methods that help to better understand the data by making complex data into an easy and readable graphs or charts which assist in decision making and, hence, increase the total quality improvement [3]. In addition, the developed charts and diagrams assist in revealing unseen causes contributing to the occurrence of defects of the system in hand in a way that causes can be tracked for a better problem solving [4].

As stated in [5], the 7 QC tools are:

- Cause and Effect Diagram,
- Check Sheet,
- Control Charts,
- Flow Chart,
- Histogram,
- Pareto Chart, and
- Scatter Diagram.

A brief description of each of these tools is presented below.

- **Pareto Chart:** also known as Pareto Diagram. It is a graphical tool that arranges the causes of a problem according to their frequency of occurrence from high to low. The chart is built based on the idea that few activities can cause most of the problems. The Pareto effect is observed when 20% of the activities are contributing to 80% of the problems [5].
- **Cause and Effect Diagram:** also known as Fishbone Diagram or Ishikawa Diagram after its inventor, Kaoru Ishikawa. It is a tool to classify and determine the causes that lead to an investigated problem in a systematic manner [5].
- **Histogram:** a graphical representation of a data set in a bar format. It is constructed by grouping the occurrence frequency of the gathered data in appropriate class intervals so that the pattern of their distribution can be revealed [5].
- **Control Charts:** graphical tools used to understand the variation observed in process performance. Such variation is categorized as unpreventable random causes and preventable assignable causes. Each control chart contains upper and lower control limits. A process is assumed to be in control if the observed variation is between these limits. Depending on the objective of the study and the type of the analyzed data, a set of the available control charts can be used for the analysis [5].
- **Scatter Diagram:** a tool used to find out whether two variables are related or not. Such relationship, if exists, might be weak or strong as well as it might be negative or positive [5].
- **Flow Chart:** a graphical tool that helps to understand the process sequence of operation by mapping and documenting the input and output for each step of the process [6].
- **Check Sheet:** a specifically designed data collection tool that helps collecting data in a systematic way. Insights obtained from the data collected by this tool depend on the factors on which the data are stratified [5].

As per [7], according to European Organization for Quality (EOQ), the current approach for using the 7 QC tools classifies them as:

- **Data Acquisition Tools:** including check sheets, histograms, and control charts, and
- **Data Analysis Tools:** including cause and effect diagrams, Pareto charts, flow charts, and scatter diagrams.

In addition, the authors proposed a model for using the 7 QC tools for quality improvement where the tools can be used, systematically, for performance monitoring, data collecting, and quality improving of the analyzed processes. The proposed model includes the six following steps:

1. Measure quality,
2. Check past and current state in process,
3. Search for root causes of selected problems,
4. Find solution,
5. Apply solution, and
6. Control.

In addition, the model contains two feedback loops: (1) for analyzing the causes of the vital few process defects, presented in Pareto chart, and (2) for continuous process improvement. Loop (1) links step 1 to step 3 of the model while considering the need of conducting step 2 for further analysis of process performance that might be required by using check sheets, control charts, histograms, and scatter diagrams. Loop (2) links step 6 back to step 1 in an effort of changing the static quality management model applied at various organizations to a dynamic one. Such change is materialized through feeding the results obtained from adopted control mechanisms, as quality measures, to the periodic reviews presented to top management about process, system, or organization performance.

The authors in [8] described all the 7 QC tools among a set of tools and approaches used in quality improvement together with examples of how each tool can be applied in healthcare settings. In addition, the application of quality control tools and techniques in hospitals was investigated by [9] where the 7 QC tools were among the tools included in the study. The survey-based study showed low utilization of these tools in hospital despite the respondents' perception of their usefulness when applied on various healthcare processes.

Finally, the literature recommends the application of the 7 QC tools as part of the Total Quality Management (TQM) adoption for performance improvement [10], illustrates a 7 QC tools-based model for performance measurement and improvement [11], and mentions the use of histograms [12,13], flowcharts [13,14], cause and effect diagrams [15], Pareto charts [13], and

control charts [16-18] in healthcare. Such efforts infer that the 7 QC tools are applied in healthcare and can help different key stakeholders to control and change in healthcare and improve the service offering to enhance patients' health.

III. The Emergency Department Layout and Processes

The ED at the public hospital under study has triage, registration, and beds areas. In addition, the beds area includes the following:

- Seven units for cardiopulmonary resuscitation (CPR) and asphyxia,
- Twelve beds for examination,
- Eight beds for observation,
- Two sortable beds,
- Eight hospitalization and recovery beds,
- One-Day Surgeries Department composed of one major and six junior operating rooms, and
- Physical Therapy Department.

The beds area is used for both surgical and medical patients without a specific designation within the area.

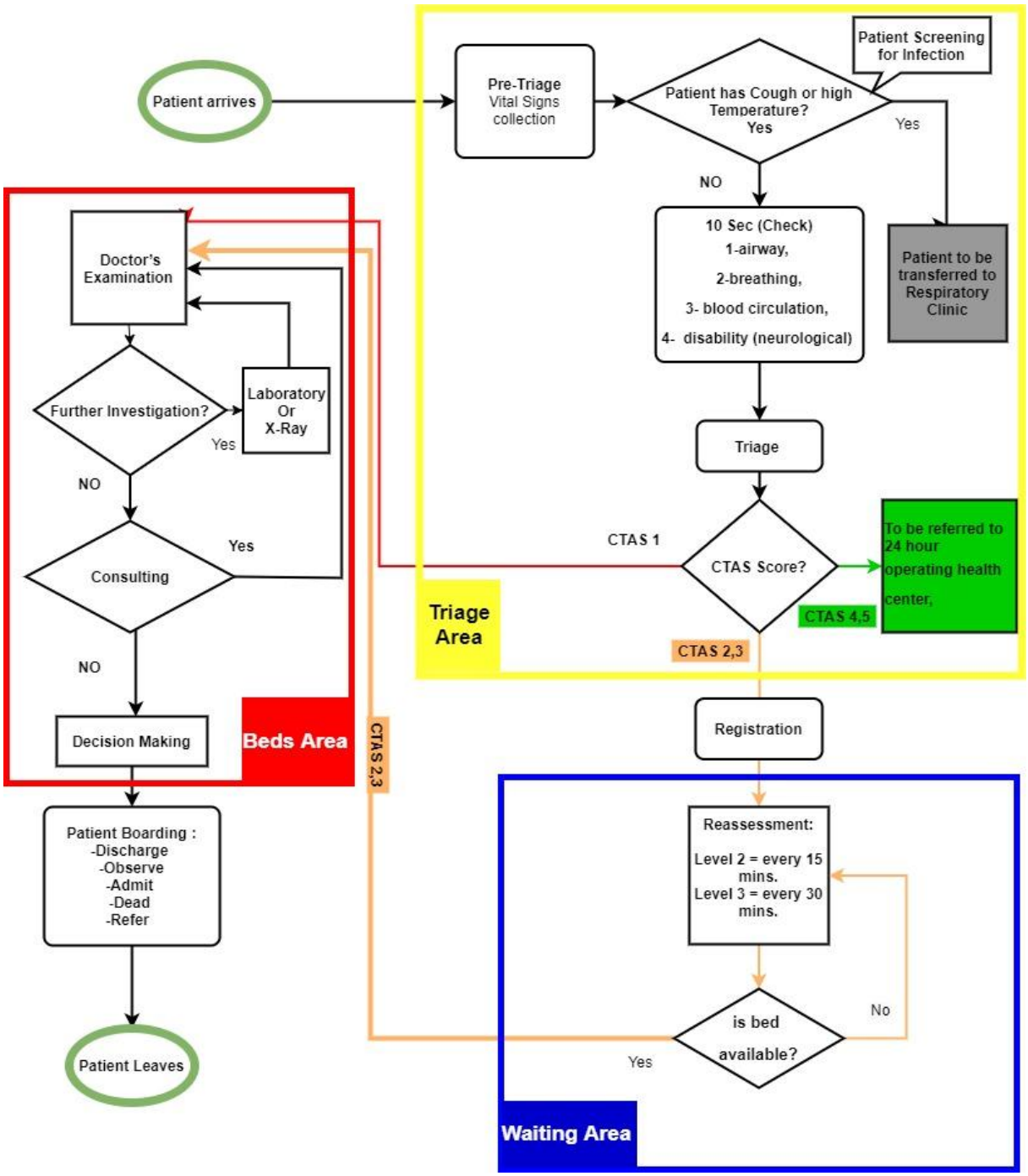

Fig. 1. Flowchart of ED Processes

The ED follows the five-level Canadian Triage and Acuity Scale (CTAS) to assign scores to the visiting patients. These levels are defined in Table 1 [19]. For better resource utilization, ED patients with CTAS4 and CTAS5 scores are filtered out from triage area by being referred to a 24-hour operating health center in the city. By doing so, only patients with 1, 2, and 3 CTAS levels will be served by the ED staff.

Table 1. The Canadian Triage and Acuity Scale

Code	Description
CTAS1	**Level 1: Resuscitation** – Conditions that are threats to life or limb.
CTAS2	**Level 2: Emergent** – Conditions that are a potential threat to life, limb or function.
CTAS3	**Level 3: Urgent** – Serious conditions that require emergency intervention.
CTAS4	**Level 4: Less urgent** – Conditions that relate to patient distress or potential complications that would benefit from intervention.
CTAS5	**Level 5: Non-urgent** – Conditions that are non-urgent or that may be part of a chronic problem.

Figure 1 presents the flowchart of the ED processes. As shown in the figure,

- Patients go to ED triage area once they arrive for pre-triage assessment and vital signs collection. This process is conducted by a triage nurse, a paramedic, or a telephone nurse where patients' blood pressure and temperature are recorded and patients' airway, breathing, blood circulation, and neurological related disabilities are checked.
- Patients who have coughing and high temperature are transferred to the respiratory clinic.
- Patients who do not have coughing and high temperature are assigned a CTAS score according to their condition.
- Patients with CTAS1 go directly to beds area to be examined by ED physicians while one of their companions does their registration concurrently or later after their condition is stabilized.
- Patients with CTAS4 and CTAS5 scores are referred to a 24-hour operating health center.
- Patients with CTAS2 and CTAS3 scores go to registration then to waiting area and stay there until beds are available at the beds area so they can be seen by ED physicians.
- While being in the waiting area, patients are reassessed at various intervals, according to their CTAS score, until beds are available in the beds area.
- While being examined by ED physicians in the beds area, and based on their condition, patients might need to be sent for lab test(s) and/or radiology procedure(s) and they might need to be seen by one of the hospital's consultants.
- Once these activities are done, decisions are made, reports are completed, and patients are boarded accordingly. The physicians' decision-making process involves the stating of one of the MOH diagnosis presented, alphabetically, in Table 2.

Table 2. MOH Diagnosis

MOH Diagnosis	MOH Diagnosis	MOH Diagnosis
Acalculous cholecystitis	Cellulitis and C.T. infections (not abscess)	Malaria
Accidents and traumas (other than RTA)	Cerebrovascular accidents	Non- bloody diarrhea (cause not defined)
Acute appendicitis	COPD and its complications	Other convulsions (not due to epilepsy or fever)
Acute bronchial asthma	Deep vein thrombosis (legs/ thigh)	Other morbidity conditions not caused by trauma and accidents
Acute bronchitis/ bronchiolitis	Diabetic keto acidosis or ketoacid tic coma	Other surgical morbidity emergencies
Acute gastroenteritis	Diabetic septic foot	Physical abuse (other than rape and domestic violence)
Acute glaucoma	Domestic violence	Poisoning with abuse of drugs
Acute intestinal obstruction	Epilepsy	Poisoning with alcohol
Acute myocardial infraction	Epistaxis (all causes except Trauma and accidents)	Poisoning with carbon monoxide
Acute otitis external/ media	Headache (all types)	Poisoning with drugs
Acute pancreatitis	Heart failure	Poisoning with insecticides
Acute pharyngitis/ tonsillitis	Hematemesis (cause not defined)	Pyrexia of unknown origin
Acute pneumonia	Hematuria	Rape
Acute pulmonary embolism	Hemoptysis (cause not defined)	Renal colic and renal stones
Acute skin hypersensitivity	Hemorrhoids and its complications	Renal failure
Acute urinary tract infections	Hypertension	Road traffic accidents (RTA)
Anal fissure and its complications	Hypoglycemia	Snake bite
Bacterial abscesses (all types)	Impaction of foreign objects within ear and nose	Swallowing of foreign objects
Burn	Jaundice (cause not defined)	Urine retention due to prostatic hypertrophy

Like all hospitals in the country, the public hospital under study assesses the performance of its various processes using ADAA indicators. The objectives of ADAA are:

- "Patient experience, safety and quality efficiency and productivity improvement,
- Performance reporting and the use of digital solutions,
- Organizational development and cultural change, and
- Improvement skills and capability" [1].

ADAA KPIs for ED include the general criteria of patients' inclusions and exclusions and sample size determination (100% if using IT system, 650 per month for manual collection). In addition, the KPIs include both definitions and formulae of Door to Doctor duration, Doctor to Decision duration, and Decision to Disposition duration. All the three durations are required to be grouped by CTAS level and the percentages of patients seen by doctor within: "immediately", 15, 30, 60 and 120 minutes respectively for patients with CTAS1, 2, 3, 4, and 5 levels are required to be reported. The KPIs also defines the percentage of non-urgent patients (CTAS4 and CTAS5) visiting the ED. Compared to the durations definitions stated in section I (Introduction), the definitions of Decision to Disposition duration and Decision to Boarding duration are different where the former one is only calculated for admitted and transferred patients while the later one includes, additionally, discharged, observed, and dead patients. This study considered the Decision to Boarding duration as the data required to calculate the Decision to Disposition duration (admitted and transferred patients) were not provided.

IV. METHOD

In this study, the 7 QC tools model, developed by [7], for quality improvement was applied to analyze the performance of the ED at the public hospital under study and provide suggestions for improvement. The application of model steps on the provided data is described below.

1. **Measure Quality:** providing insights about the performance of various processes within the ED in regard to patients' demographic data and their CTAS levels in addition to assessing the performance level of ADAA KPIs against the stated targets. This was conducted on data collected by the ED staff in the first half of February 2019. Prior to conducting the analysis, the provided data were validated where any record that is incomplete or has missing data regarding Door to Doctor, Doctor to Decision, Decision to Boarding, or Triage to Boarding durations was eliminated.
2. **Check Past and Current State in Process:** analyzing process performance using a set of appropriate 7 QC tools to identify process defect(s) that may exist.
3. **Search for Root Causes of Selected Problem:** constructing cause and effect diagram and identifying the vital causes behind the observed defects.
4. **Find Solution:** proposing solutions for the identified issues.
5. **Applying Solution:** proposing methods for applying the proposed solutions.
6. **Control:** proposing control mechanisms to maintain the expected gains of applying the proposed solutions.

IV. RESULTS AND DISCUSSION

This section illustrates the results obtained while conducting the stated steps of the methodology applied together with their related discussion.

IV.I Measuring Quality

The analysis techniques were applied on data collected in the first half of February 2019. Table 3 presents the number of valid and invalid medical recoded numbers (MRNs) of each day of the analyzed period. An MRN is considered invalid if it is blank, has wrong data entry, or has missing data regarding Door to Doctor, Doctor to Decision, Decision to Boarding, or Triage to Boarding durations within the designated spreadsheet of the provided data.

Figure 2 shows patients' demographic data of the ED visitors included in the study where 1750 (58%) were Saudi males, 941 (31%) Saudi females, 270 (9%) non-Saudi males, and 59 (2%) non-Saudi females.

Figure 3 presents the classification of ED visitors according to their assigned CTAS scores where 4 (0.13%) of the total visitors included in the study were classified as level 1, 46 (1.52%) as level 2, 1851 (61.3%) as level 3, 1058 (35.03%) as level 4, and 61 (2.02%) as level 5 of the CTAS. Thus, 63% of the ED visitors were of CTAS1, CTAS2 and CTAS3 levels and 37% were of CTAS4, and CTAS5 levels.

Table 3. Number of Daily Data Points Included in the Study

Day	Total	Number of Invalid MRNs	Number of Valid MRNs
1	263	49	214
2	245	61	184
3	309	100	209
4	267	70	197
5	328	76	252
6	306	102	204
7	289	75	214
8	272	46	226
9	290	38	252
10	311	73	238
11	270	58	212
12	300	87	213
13	314	94	220
14	298	113	185
Total	4062	1042	3020

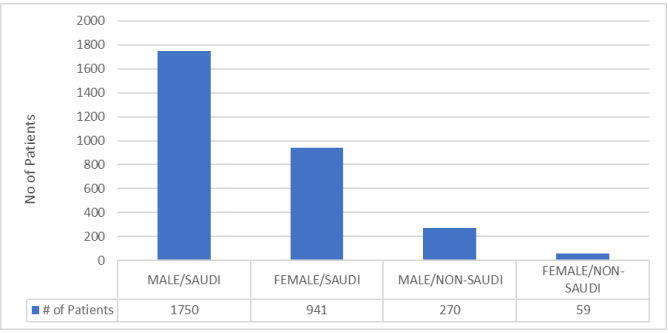

Fig 2. ED Visitors' Demographic Data

According to ADAA KPIs of ED performance, collected data include all patients, including non-eligible ones, except

deceased patients during visit, patients who left ED without being seen, and patients who left against physicians' advice. In addition, the ED reports ADAA KPIs through a manual selection of 650 patients out of the total number of ED visitors per month. This is done by using the systematic random sampling technique where a patient out of three consecutive patients in patient data Excel sheet is selected until the determined sample size is reached.

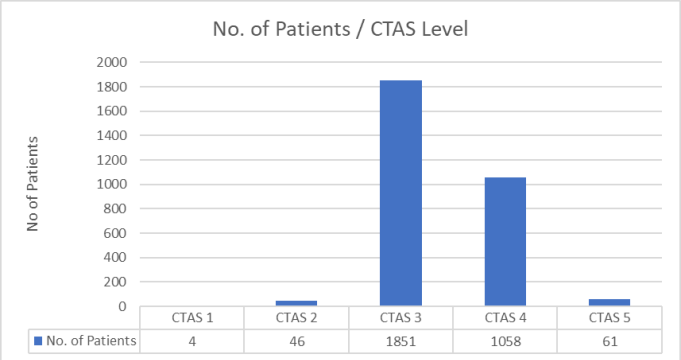

Fig 3. Number of Patients Based on CTAS Level

This study considered analyzing all valid MRNs, 3020, of the available data, instead of analyzing a sample selected through using the stated sampling technique, so that more insights can be gained about the ED performance. The total time spent by ED visitors is presented in Figure 4. The average LOS of ED visitors is more than 120 minutes with more than 100 minutes standard deviation. In addition, the data show that the LOS ranges between 6 minutes and almost one day. Moreover, as the median, 105 minutes, is smaller than the average LOS, data are skewed to the right and have a positive excess kurtosis (i.e. leptokurtic). Furthermore, the data do not form a normal distribution since the P-value of Anderson-Darling Normality Test is <0.005.

Table 4 shows the Door to Doctor KPI duration, which includes the time spent in triage, registration, and waiting areas grouped by CTAS level while including the percentage of patients seen by an ED physician within "immediately", 15, 30, 60, 120 minutes for CTAS1, 2, 3, 4, and 5 levels respectively.

Table 5 shows the Doctor to Decision KPI duration, which includes patient examination, lab test, radiology procedures, further consultation, and report writing grouped by CTAS level.

Table 6 shows the Decision to Boarding KPI duration, which covers the period from report writing until patient's boarding.

Finally, regarding the percentage of nonurgent patients which the ED is requested to report to ADAA, percentage of Ed visitors with CTAS4 and CTAS5 levels, as per the data shown in Figure 3, is 37%.

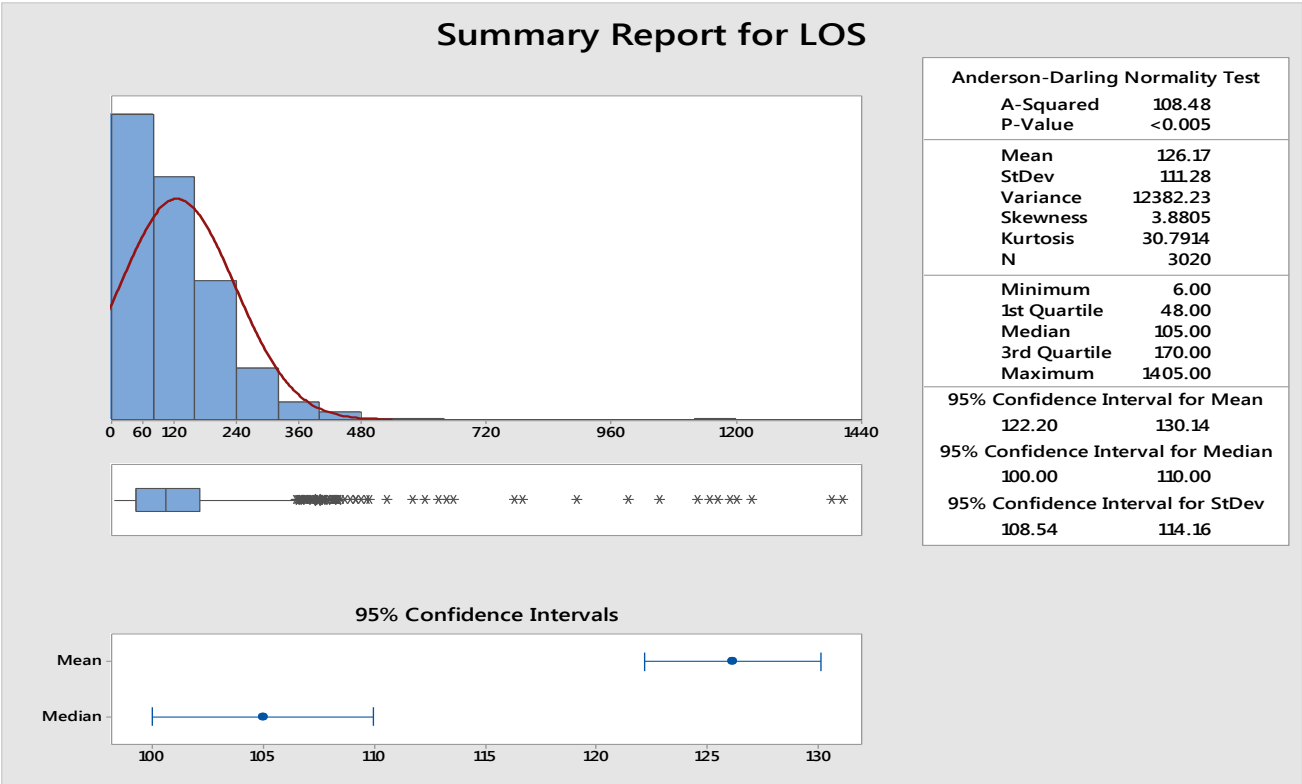

Fig. 4. Triage to Boarding Duration Summary Report (Minutes)

Table 4. Door to Doctor Duration Summary Report Grouped by CTAS Level (Minutes)

Item	CTAS1	CTAS2	CTAS3	CTAS4	CTAS5
Number of Patients	4	46	1851	1058	61
Mean	1.75	16.39	25.19	19.18	20.00
Median	1.00	10.00	15.00	12.00	15.00
Std. Dev.	1.50	26.00	51.01	21.54	19.03
Minimun	1.00	1.00	1.00	1.00	1.00
Maximum	4.00	163.00	1098.00	220.00	115.00
% of Patients Seen Per CTAS Specified Time Frame	100.00	67.40	79.40	94.60	100.00

IV.II Evaluating Process Performance

The evaluation of the performance of various processes at the ED starts with evaluating the data collection method followed by the ED processes' level of performance against ADAA KPIs. Then the analysis will relate the observed performance levels to various factors such as CTAS levels and MOH diagnoses.

The manual selection of patients that form the sample size required to report the ED performance against ADAA KPIs, instead of including 100% of data, indicates that the ED does not have an IT system in place through which they perform this activity to include all patients visiting the ED. The quality of this manual collection process can be assessed by constructing the p-chart, Figure 5, of the number of invalid MRNs in the provided data shown in Table 3. The Laney p-chart was constructed instead of the normal p-chart based on the results of the p-chart diagnostic test, Figure 6, for over-dispersion and under-dispersion effect of the data on chart control limits.

The Laney p-chart was constructed by using the total number of MRNs of each day as the subgroup size instead of using the average number of MRNs per day.

Table 5. Doctor to Decision Duration Summary Report Grouped by CTAS Level (Minutes)

Item	CTAS1	CTAS2	CTAS3	CTAS4	CTAS5
Number of Patients	4	46	1851	1058	61
Mean	113.50	161.65	112.86	46.42	32.85
Median	82.00	140.00	105.00	27.00	19.00
Std. Dev.	91.90	95.26	90.41	72.50	36.14
Minimun	44.00	3.00	0.00	0.00	2.00
Maximum	246.00	495.00	1315.00	1380.00	165.00

Table 6. Decision to Boarding Duration Summary Report Grouped by CTAS Level (Minutes)

Item	CTAS1	CTAS2	CTAS3	CTAS4	CTAS5
Number of Patients	4	46	1851	1058	61
Mean	92.50	83.07	17.46	8.19	8.43
Median	115.00	60.00	5.00	5.00	5.00
Std. Dev.	63.97	82.10	29.85	44.77	12.22
Minimun	0.00	3.00	0.00	0.00	1.00
Maximum	140.00	300.00	245.00	1440.00	70.00

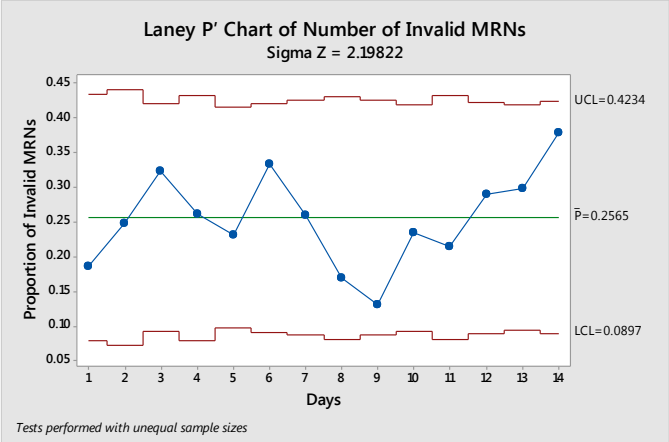

Fig. 5. P Chart of Number of Invalid MRNs

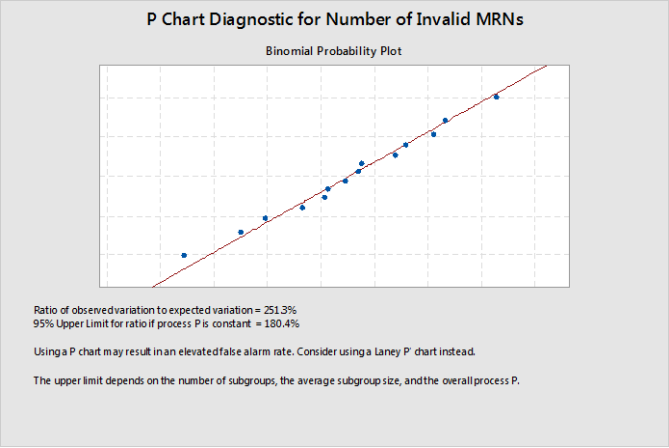

Fig. 6. P Chart Diagnostic Test of Number of Invalid MRNs

As inferred from the chart, and due to the fact that all data points fall between upper and lower control levels, the data collection process has a stable performance level with an average defect level of invalid MRNs equals 0.26 with a 0.42 upper control limit and a 0.09 lower control limit. The stable performance level of the process shows that the current collection system is incapable of producing lower number of invalid MRNs, i.e. less than 26%, which indicates a need for a system-level improvement initiative in order to enhance the quality of the data collection method followed in the ED. The

invalid MRNs, generated by currently adopted data collection process, are the ones that cannot be included in reporting ADAA related KPIs due to having blank cells, wrong data entry, or having missing data regarding Door to Doctor, Doctor to Decision, Decision to Boarding, or Triage to Boarding data cells within the designated spreadsheet of the collected data. A check sheet was generated to identify the causes behind generating invalid MRNs due to recorded clock time "Spreadsheet Formulation Issues" and "Wrong Data Entry" where the findings are summarized in Table 7.

Further analyses have been conducted to study the relationship between the observed levels of invalid MRNs and the total number of MRNs per day as well as the weekday by plotting the related scatter diagrams, Figures 7 and 8, and conducting Pearson correlation analysis. Figure 8 indicates that the lowest number of invalid MRNs is observed on Fridays while the highest number of MRNs is observed on Thursdays. The figure also shows that the level of variability observed in number of invalid MRNs for each weekday is the lowest on Fridays and the highest on Thursdays.

In addition, Figure 9 presents the summary of the conducted Pearson correlation analysis.

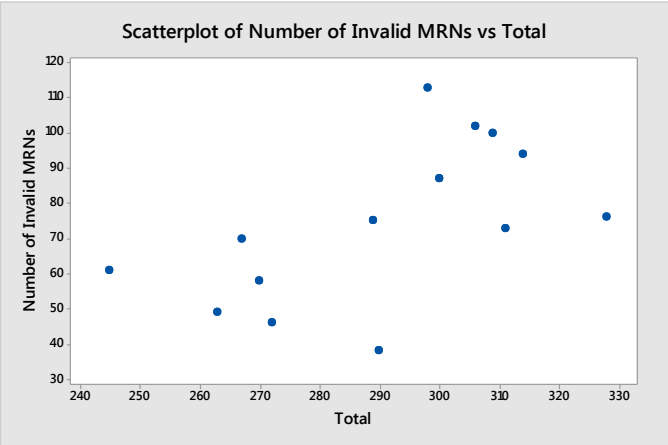

Fig. 7. Scatter Diagram of Number of Invalid MRNs vs Total MRNs Per Day

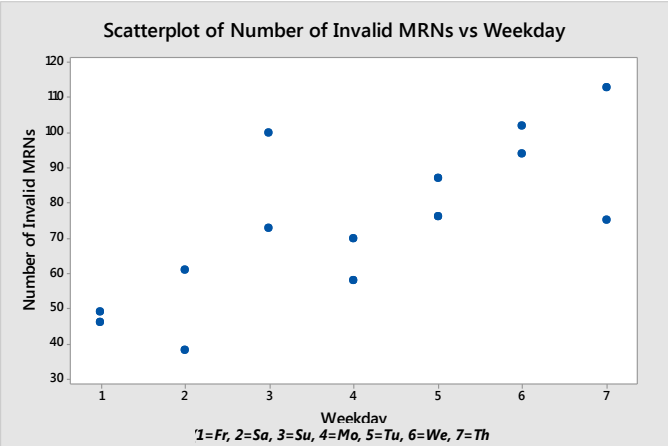

Fig. 8. Scatter Diagram of Number of Invalid MRNs vs Weekday

Table 7. Identified Causes behind Generating Invalid MRNs

Type	Description	Quantity	Affected Duration			
			Door To Doctor	Doctor To Decision	Decision To Boarding	Triage To Boarding
Spreadsheet Formulation Issues	Wrong calculation when triage time = time seen	53	X			
	Wrong calculation when triage time is PM and time seen is AM	46	X			
	Wrong calculation when time seen is before triage time	50	X			
	Wrong calculation when time seen = decision time	6		X		
	Wrong calculation when decision time = boarding time	10			X	
Wrong Data Entry	Triage time	3	X			X
	Time seen	8		X		X
	Decision time	12		X	X	X
	Boarding time	3			X	X

The results show that there is a positive correlation between the number of daily invalid MRNs and the total number of daily MRNs and the weekday for α=0.05 and α=0.01 respectively.

Correlation: Day, Total, Number of Invalid MRNs, Number of Valid MRNs, Weekdays

	Day	Total	Number of Invalid MRN	Number of Valid MRN
Total	0.391 0.167			
Number of Invalid MRN	0.307 0.286	0.587 0.027		
Number of Valid MRN	0.107 0.715	0.488 0.076	-0.419 0.135	
Weekday	0.496 0.071	0.524 0.054	0.756 0.002	-0.227 0.435

Cell Contents: Pearson Correlation
P-Value

Fig. 9. Summary of Pearson Correlation Analysis

Such correlation between total number of MRNs and number of invalid ones might shed the light on the effect of the level of workload on the quality of data collection method and might

suggest the need of implementing a more effective data collection technique (i.e. automating the process by using bar code readers supported by a mobile-based application or adopting Internet of Things (IOT) based solution) that improve the situation and frees the ED staff to provide better services to the patients.

In addition, the correlation between the weekday and the invalid number of MRNs might suggest weekday related factors such as the number and health condition of patients visiting the ED and/ or the number and characteristics of staff on duty at each weekday.

When considering the CTAS levels of ED visitors presented in the analyzed data, Figure 3, it can be inferred that the practice of transferring patients of CAS4 and CTAS5 levels to a 24-hour operating health center is not fully applied as patients of these levels represent 37% (1119 out of 3020) of the data. The proper transfer of such number of visitors to the designated health center will free up ED resources and improve both ED capacity and productivity to serve more visitors of CTAS1, 2, and 3 levels.

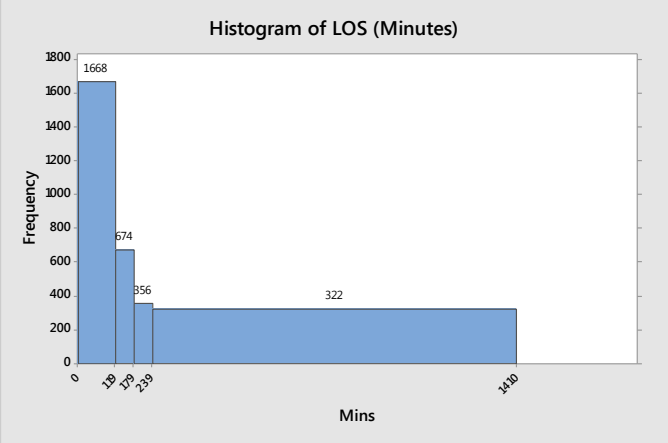

Fig. 10. Histogram of LOS (Minutes)

Regarding the LOS of ED visitors, Figure 4 showed that patients spend, on average, a little more than 120 minutes while their LOS ranged from 6 minutes to almost one day (1405 minutes). The histogram presented in Figure 10 shows that 55% (1668) of ED visitors have two hours or less LOS, 22% have two to three hours LOS, 12% have three to four hours LOS,11% have four to twenty hours LOS, and less than 1% have twenty to twenty-four hours LOS. Thus, a total of 45% of patients have more than 120 minutes LOS. These cases need to be further analyzed.

Table 8. Total Number of Patients' Distributed over the ED Daily Operating Time

Night (00:00-08:00)	Morning (08:00-16:00)	Afternoon (16:00-00:00)
630	1120	1270
21%	37%	42%

Table 8 shows the total number of patients distributed over the ED daily operating time. 21% of the patients visit the ED in the night shift, 37% visit the ED in the morning shift, and 42% visit the ED afternoon shift with 79, 140, and 159 patients' rate of arrival per hour during the three shifts respectively. Such fluctuation in number of patients visiting the ED in these various shifts might dictate the need of varying the staffing level according to the fluctuating demand to have the patients served effectively. A more detailed view about the number of patients per hour visiting the ED during the study period is presented in Figure 11 starting from midnight. The figure illustrates further variation in patients' rate of arrival per hours during each shift where the range of such rate is 92, 88, and 78 patients per hour for the night, morning, and afternoon shifts respectively.

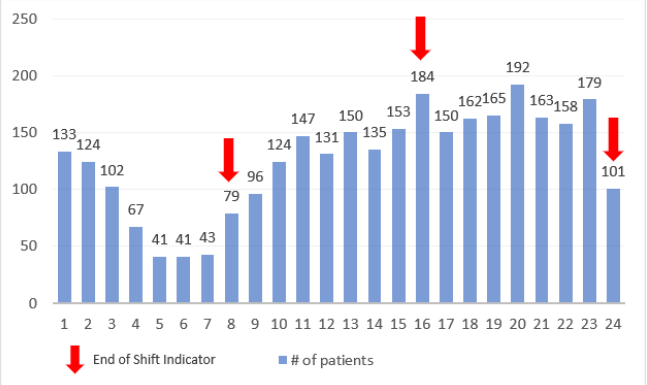

Fig. 11. Number of Patients Per Hour Visiting the ED

Figure 12 shows the LOS categorized based on the major components defining the Triage to Boarding duration. As shown in the figure, 18% of the LOS is Door to Doctor duration, 70% is Doctor to Decision duration, and 12% is Decision to Boarding duration. Although most ED visitors' LOS is spent in Doctor to Decision time, within which mostly value adding activities are conducted, activities within this duration might require more analysis to explore opportunities for a significant improvement level of the offered services comprising these activities. As the provided data do not include sufficient insights about activities conducted in this duration, causes behind any increase in the LOS due to these activities have been investigated through brainstorming sessions and individual interviews with key ED staff and the results are illustrated in section IV.III.

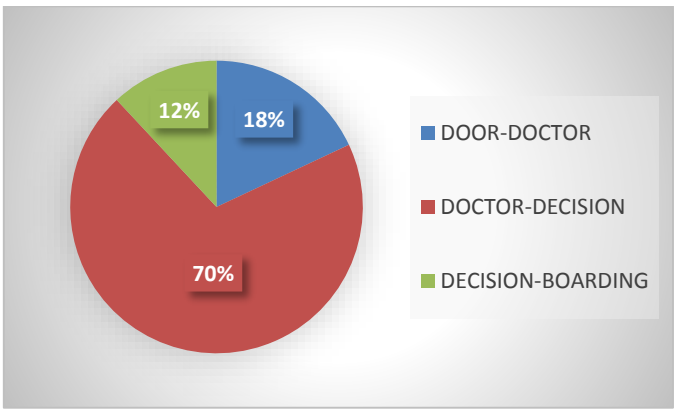

Fig. 12. Components of ED Visitors' LOS

The performance level of ED processes conducted during the Door to Doctor duration can be assessed according to the time spent by various CTAS levels, Table 4, and having that

compared to ADAA KPIs. All patients with CTAS levels 1 (4 patients) and 5 (61 patients) were seen by ED physicians within ADAA specified periods, 5 and 120 minutes respectively. However, 67.4%, 79.4%, and 94.6% of patients with CTAS levels 2, 3, and 4 were seen by ED physicians within ADAA specified periods, 15, 30, and 60 minutes respectively. The low performance level of the ED regarding the percentage of patients with CTAS2 and CTAS3 levels seen by ED physicians within ADAA specified period compared to other CTAS levels requires more investigation. One of the reasons behind this might be the service offered to patients with CTAS4 and CTAS5 whom should be transferred to the 24-hr operating health center instead of being served by the ED staff. The data also show some extreme values especially for CTAS2, 3, and 4 levels that might require further investigation.

Tables 5 and 6 show the Doctor to Decision and Decision to Boarding durations grouped by CTAS level. There is an observed variation in the mean value of these times as well as the observed maximum time for each CTAS level.

Table 9. The Average Durations of LOS Components per CTAS Level (Minutes)

Item	CTAS1	CTAS2	CTAS3	CTAS4	CTAS5
Number of Patients	4	46	1851	1058	61
Door to Doctor Mean	1.75	16.39	25.19	19.18	20.00
Door to Doctor Mean (%)	0.84	6.28	16.20	26.00	32.64
Doctor to Decision Mean	113.50	161.65	112.86	46.42	32.85
Doctor to Decision Mean (%)	54.63	61.91	72.57	62.9	53.61
Decision to Boarding Mean	92.50	83.07	17.46	8.19	8.43
Decision to Boarding Mean (%)	44.52	31.81	11.23	11.1	13.75
Mean LOS (Triage to Boarding)	207.75	261.11	155.51	73.79	61.28
Mean LOS of All Patients Per CTAS	831	12,011	287,849	78,070	3,738
Mean LOS of All Patients Per CTAS (%)	0.21	3.14	75.25	20.4	1

The mean value of Doctor to Decision duration varies from 33 minutes, for CTAS5 level, to 162 minutes, for CTAS2 level, while the mean value of Decision to Boarding duration varies from 8 minutes, for CTAS4 level, to 93 minutes for CTAS1 level.

Table 9 shows the mean times of various durations composing the LOS gathered from Tables 4, 5, and 6. As shown in the table, although they have the longest mean LOS, the mean LOS of CTAS1 and 2 patients represents only 3.35% of the mean LOS of all patients which minimizes their impact on the mean LOS of all CTAS levels, 126.17 minutes, shown in Figure 4. On the other hand, the relatively short mean LOS of patients with CTAS4 and 5 levels have pulled the mean of LOS of all CTAS levels to the observed level, 126.17, since the mean LOS of CTAS4 and 5 patients represents 20.5% of the mean LOS of all patients. Should patients with levels of CTAS4 and 5 are transferred to the 24-hour operating health center, the mean LOS of all CTAS levels will be close to that of CTAS3, 155 minutes, since they would represent almost 97% of the mean LOS of all patients instead of 75% as it is observed now.

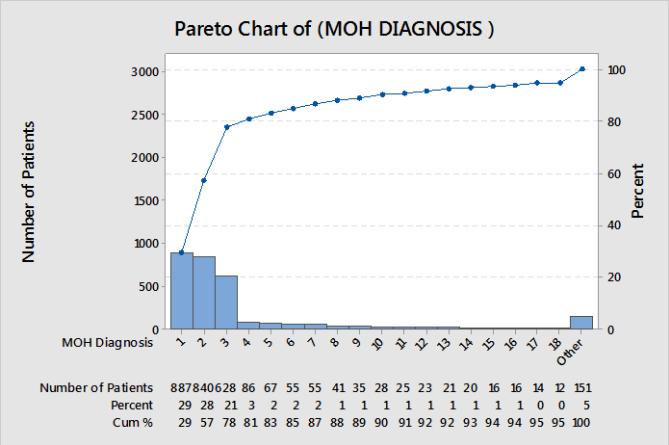

Fig. 13. Pareto Chart of MOH Diagnoses

When analyzing the data according to the MOH diagnoses, Figure 13 together with Table 10, it can be inferred that 78% of the patients visiting the ED are diagnosed as (listed in a descending order):

- Other morbidity conditions not caused by trauma and accidents,
- Accidents and traumas (other than RTA), or
- Other surgical morbidity emergencies.

Tables 11, 12, and 13 show the number of patients diagnosed with these conditions grouped by CTAS level. From these tables, it can be concluded that 16.46% (146) of the patients diagnosed with other morbidity conditions not caused by trauma and accidents, 72.71% (610) of the patients diagnosed with accidents and traumas (other than RTA), and 41.31% (259) of the patients diagnosed with other surgical morbidity emergencies are of levels CTAS4 and CTAS5. The total number of these patients (1015) represents 91% of the total number of patients with CTAS4 and CTAS5 levels (1119) visiting the ED. Thus, should the process of transferring these cases to the 24-hour operating health center was feasible, the transfer of such cases would have provided better utilization of ED resources to serve patients with CTAS1, 2, and 3 levels. However, if such transfer was not feasible due to patients' health condition, this might indicate the practice of down

triaging patients' level, assigning patients CTAS levels lower than what their health condition indicate [20], due to considering ED operating conditions. As a result, the performance level of ED operations would be, exceedingly, enhanced by allowing for longer LOS for those patients who have been down triaged. Tables 11, 12, and 13 also show that 71% of the patients diagnosed with the three listed diagnoses are patients with CTAS3 level indicating that the LOS of patients with these three diagnoses will highly impact the mean LOS of CTAS3 patients and the overall mean LOS of patients all CTAS levels. Thus, it might be appropriate for ED staff to further analyze the LOS of CTAS3 patients diagnosed with other morbidity conditions not caused by trauma and accidents, accidents and traumas (other than RTA), and other surgical morbidity emergencies in order to enhance the mean LOS of all ED patients.

Table 10. MOH Diagnoses Check Sheet Arranged in a Descending Order

#	MOH Diagnosis	Number of Patients	%
1	Other morbidity conditions not caused by trauma and accidents	887	29
2	Accidents and traumas (other than RTA)	840	28
3	Other surgical morbidity emergencies	628	21
4	Road traffic accidents	86	3
5	Renal colic and renal stones	67	2
6	Headache (all types)	55	2
7	Physical abuse (other than rape and domestic violence)	55	2
8	Acute appendicitis	41	1
9	Bacterial abscesses (all types)	35	1
10	Acute gastroenteritis	28	1
11	Hypertension	25	1
12	Acute bronchial asthma	23	1
13	Burn	21	1
14	Epilepsy	20	1
15	Heart failure	16	1
16	Pyrexia of unknown origin	16	1
17	Acute pneumonia	14	0.46
18	Cerebrovascular accidents	12	0.4

IV.III Identifying Root Causes

Data provided were used to analyze the performance of ED at the public hospital under study based on ADAA KPIs, patients' classification according to CTAS levels, and MOH diagnoses. Analyzing the data from these perspectives have identified several causes behind the observed level of LOS.

These causes are:

- Imprecise manual data collection method,
- Lack of implementing ED procedures (CTAS4 and CTAS5 patients' referral process),
- Not meeting ADAA Door to Doctor duration KPI for CTAS2, CTAS3, and CTAS4 patients,
- Less than optimum level of % non-urgent patients ADAA KPI (37%),
- Fluctuation in workflow at various shifts and on hourly basis of operation, and
- Up/ Down triaging practice.

Table 11. Number of Patients Diagnosed with Other Morbidity Conditions Not Caused by Trauma and Accidents Grouped by CTAS Level

Other Morbidity conditions not Caused by Trauma and Accidents	Number of Patients	%
CTAS1	2	0.23
CTAS2	25	2.82
CTAS3	714	80.50
CTAS4	131	14.77
CTAS5	15	1.69
Total	887	100

Table 12. Number of Patients Diagnosed with Accidents and Traumas (Other than RTA) Grouped by CTAS Level

Accidents and Traumas (other than RTA)	Number of Patients	%
CTAS1	0	0.00
CTAS2	0	0.00
CTAS3	229	27.29
CTAS4	609	72.59
CTAS5	1	0.12
Total	839	100

Table 13. Number of Patients Diagnosed with Other Surgical Emergencies Grouped by CTAS Level

Other Surgical Morbidity Emergencies	Number of Patients	%
CTAS1	0	0.00
CTAS2	3	0.48
CTAS3	365	58.21
CTAS4	218	34.77
CTAS5	41	6.54
Total	627	100

The analyses also covered major LOS components (Door to Doctor, Doctor to Decision, and Decision to Boarding durations) which are all forming the Triage to Boarding Time. As not much information was inferred from data provided about specific durations or conditions of the processes conducted within these durations, several brainstorming sessions and individual interviews have been conducted with key ED staff to get more insight about what these processes are, how long they take on average, and how they are usually performed. Most of the interviews covered, mostly, processes related to Doctor to Decision LOS component as it represents, on average, 70% of the total time spent by patients at the ED. The Doctor to Decision duration involves conducting the processes presented in Figure 14.

Both interviews and brainstorming sessions revealed that among the causes behind the observed level of LOS within this major LOS component are:

- Human resources availability (consultants, physicians, and nurses),
- Human resource competency (ability to operate medical devices),
- Patient transfer to/ from lab department,
- Patient transfer to/ from radiology department,
- Lab results waiting time,
- Radiology exam results waiting time,
- Medical staff motion within ED,
- Medical staff motion to get pharmacy supplies,
- Medical devices availability,
- Medical devices failure,
- Medical supplies availability,
- Distance to lab,
- Distance to radiology,
- Distance to pharmacy,
- ED space allocation (surgical vs medical sections)
- Admission order limitation (only done through consultants),
- Bed turnaround procedure, illustrated in Figure 15, which affects bed turnaround time,
- Patient data (missing basic data, lab test/radiology exam results, or timings),
- ED shift handover procedure (Between 10 and 24 patients. End of shift periods are labeled in Figure 11),
- Customer (both internal and external)/ staff interaction,
- Report writing (manual process with missing data related to patients' results and process timings), and
- Power shutdown.

The Fishbone diagram presented in Figure 16 includes all identified causes behind the observed LOS level categorized into six main categories: Man, Machine, Methods, Measurement, Materials and Environment.

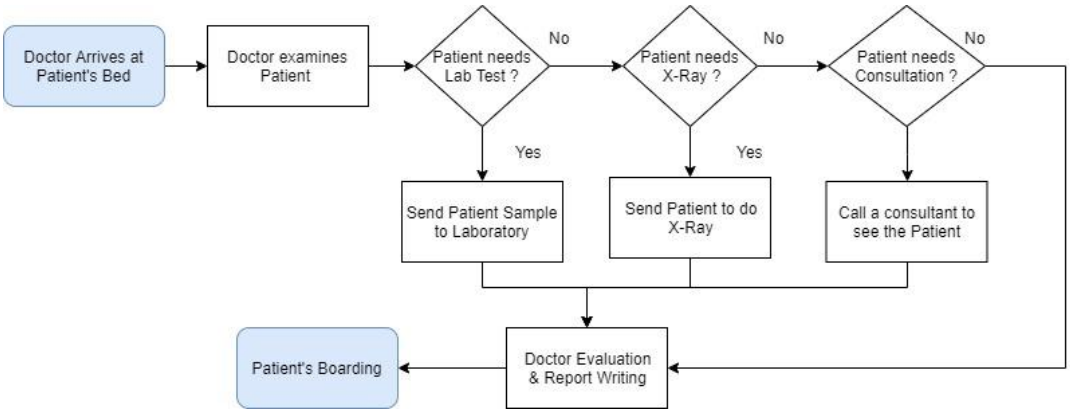

Fig. 14. Doctor to Decision Flowchart

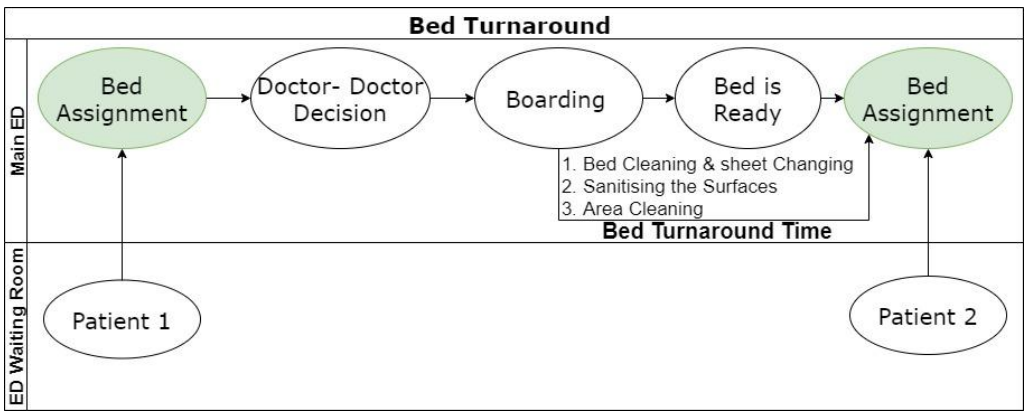

Fig. 15. Bed Turnaround Process

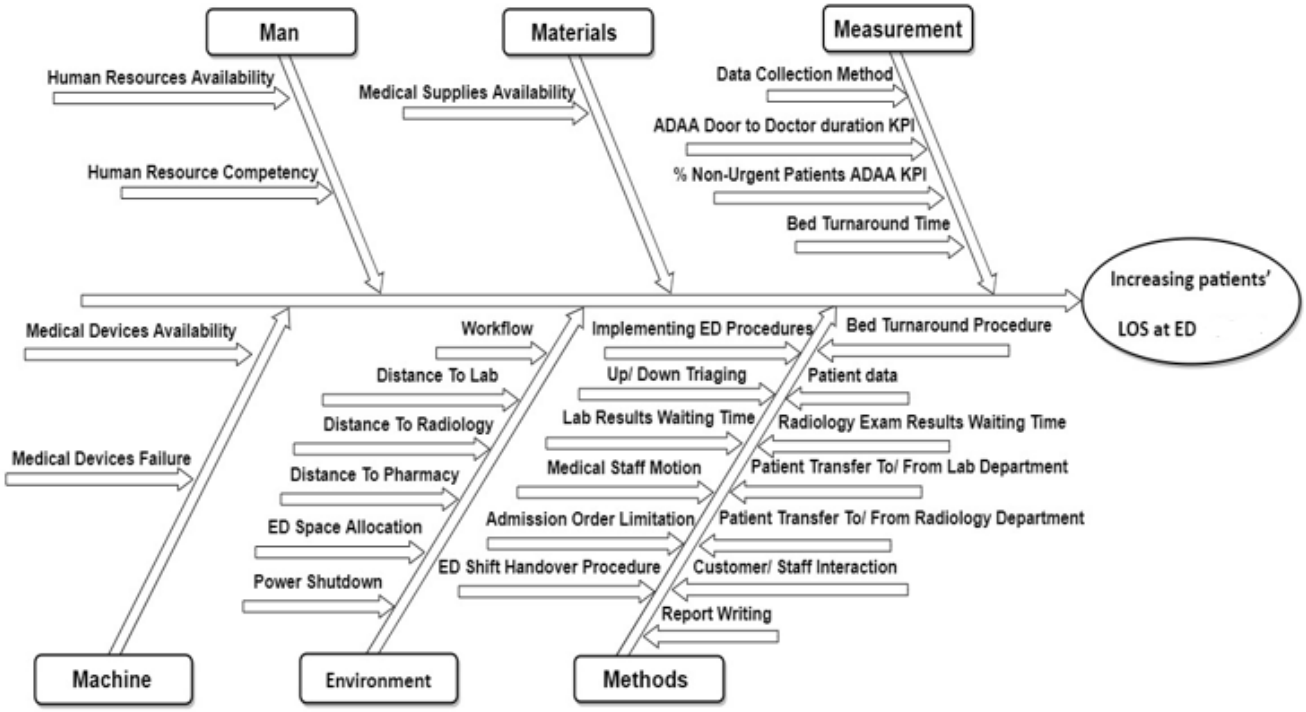

Fig. 16. Fishbone Diagram

IV.IV Proposed Solutions

Now that several root causes of the observed level of ED LOS have been identified, a set of proposed solutions to enhances the related processes could include the following:

- Enhancing data collection method,
- Adhering to CTAS4 and CTAS5 patients' referral process,
- Adjusting staffing level to patients' workflow,
- Enhancing triaging process,
- Enhancing human resource competencies,
- Implementing medical devices maintenance program,
- Enhancing ED space utilization,
- Revising procedures of admission, bed turnaround, and shift handover,
- Defining customer/ staff interaction protocols, and
- Enhancing report writing.

IV.V Implementation Strategies

This section presents suggested strategies for implementing the proposed solutions.

- **Enhancing data collection method:** The are various approaches to enhance the data collection method ranging from fixing spreadsheet formulation issues and precisely entering timing data, of the currently adopted manual collection method, to fully automating the process and have it feeding the ED information system with relevant data. The process automation could be obtained by using bar code readers supported by a mobile-based application or adopting Internet of Things (IOT) based solution that improve the situation and frees the ED staff to provide better services to the patients. The ED also could adopt one of the available patient tracking/ flow solutions to enhance the process.
- **Adhering to CTAS4 and CTAS5 patients' referral process:** Number of non-urgent cases can be reduced by placing a physician in triage area to make a quick assessment and support the implementation of the patients' referral process which will result into preventing such cases to be seen by the ED physicians at later stages of the patients' care process.
- **Adjusting staffing level to patients' workflow:** Forecasting models can be built to predict future patients' workflow based on related historical data. Once this is determined, staffing level can be adjusted accordingly.
- **Enhancing triaging process:** Placing a physician in triage area together with further analyzing the activities conducted in triage area will provide a set of counter measures that enhance the overall process especially those aspects related to up/down triaging practices.
- **Enhancing human resource competencies:** The ED staff is recommended to be cross trained on devices used in various healthcare processes.
- **Implementing medical devices maintenance program:** Each device within ED area is required to have a log file with the following information:
    - User manual,
    - User cleaning instructions,

- Maintains schedule, and
- Contact info of maintenance staff member.

Devices' log files should be stored in a central location and access should be granted to all users. However, a single point of contact is needed to coordinate both scheduled and corrective maintenance related activities with maintenance department.

- **Enhancing ED space utilization:** Guided by the top types of MOH diagnoses, The ED can rearrange the floor layout in favor to the majority of the diagnosed cases which will result in better utilization of available resources.
- **Revising procedures of admission, bed turnaround, and shift handover:** Each of these processes requires further analysis, through such techniques as kaizen projects, to identify the current performance baseline and provide suggestions for improvement.
- **Defining customer/ staff interaction protocols:** As ED staff interacts with patients, patients' companions, and other departments staff members, they need to have a protocol that govern such interaction, unify the type of response of various ED staff members, and provide a clear description of the escalation process that might be required.
- **Enhancing report writing:** Replacing the current manual report writing process with a computer-based one where required data will be stored in a central location so that report related data can be automatically retrieved when needed.

IV.VI Control Strategies

As ADAA KPIs for the ED at the public hospital under study provided significant insights when provided data were analyzed against them, they do form a great mechanism for controlling various ED processes. Both continuous monitoring and sharing the performance of ED against these KPIs will increase the awareness about the level of performance among the ED staff, keep the ED management informed, and energize them all to be engaged in endless cycles of continuous improvement.

VI. CONCLUSION

This study supports the claim that the 7 QC tools can play a significant role in quality improvement in hospitals where management can use them to find and troubleshoot quality related issues. This was done through applying the tools to improve patient experience at the emergency department of one of the Saudi public hospitals. The study described how the tools were employed to analyze the status quo and identify opportunities for improvement from the first step when patients enter the ED until boarding. As a result, several root causes of the observed level of ED LOS have been identified. Accordingly, a set of solutions to enhance the related processes was proposed together with implementation strategies.

Nonetheless, some limitations in this study should be noted. First, the conducted analyses were, mostly, based on patients CTAS levels and overall durations of major LOS components without considering both nature and duration of various subprocesses that are composing each component. The unavailability of related data and the inability of authors to have them collected represented a limitation in the study. Having more details about the durations of ED subprocesses might have provided additional useful insights for their improvement. Second, the amount of provided data as well as the duration which it reflects might limit any generalization of obtained conclusions. Thus, a larger data set that reflects the ED performance throughout the year might provide more insights about the department performance and help in discovering any seasonal effect, a natural phenomenon at emergency departments, on overall system's performance. Finally, the unavailability of ED staff to, adequately, meet with the authors, due to being always busy performing their duty, represented a limitation in obtaining detailed information about the operation of various ED processes. Future studies might consider forming joint teams of researchers and ED staff members with dedicated meeting times to, adequately, analyze the investigated ED processes.

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