Statistical analysis of the researches carried out on Lean and Six Sigma applications in healthcare industry

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Abstract: The Lean and Six Sigma are two complementary methodologies in the sense that Lean focuses on reducing waste and increasing speed; whereas Six Sigma focuses on reducing variations and increasing consistency. The purpose of this paper is to provide an overview of Lean and Six Sigma applications in the healthcare sector. The work done by many researchers in healthcare industry is discussed. Literature survey shows that most of the studies (42%) are focused on reducing processing time. It is also found that number of studies focused on reducing processing time never goes out of phase. The Pareto chart analysis was performed for number of studies in various countries and different departments. It is found that more than 50% of studies were carried out in the USA only and 22% of the studies were performed in emergency department in various countries. The matrix plots are shown for number of studies in different countries and different departments throughout the time line starting from the year 2000 to till date. It is also found that Lean and Six Sigma methodologies were uniformly applied in emergency and surgery departments, whereas in case of countries; only the USA shows continuous applications of Lean and Six Sigma techniques.

Keywords: Lean and Six Sigma; quality in healthcare; processing time; productivity; length of stay.

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1 Introduction

Healthcare quality is a matter of serious concern as investment is continuously increasing in this field worldwide with little interest towards quality. More emphasis is given on improving healthcare quality since 2000 because several reports issued by the US Institute of Medicines (IOM) which clearly highlight the importance of building safe and effective healthcare system. In one of its report, released in November 1999, the authors estimated that around 98,000 patients die each year due to medical errors. According to the Health Department of UK (2001), approximately £2 billion per annum is being paid due to adverse incidents and clinical negligence claim. Annual seminars organised by healthcare federation of India NATHEALTH (2017) reported the following facts:

1 16% of global share of maternal deaths and 27% of global new born deaths still accounts by India.

2 There is continuously growth in deaths due to communicable diseases with 22% of global TB incidence in India.

3 The 60% of deaths in India is due to non-communicable diseases.

These reports illustrate that there is a huge demand of quality in healthcare throughout the globe. The certain amount of investment is required to meet the quality standards. From the World Bank data of 2014 on healthcare expenditure, it is found that total healthcare expenditure is approximately 10% of the world GDP. If we specifically talk about India, then Indian government spends only 1.5% of its GDP on healthcare which is among the lowest globally compared to other countries. It is important to know that the USA spends around 9% of its GDP on healthcare sector. So it is clear from these facts and reports that healthcare system needs both investment as well as quality to meet the ultimate objective of patient satisfaction. As healthcare is a service organisation and every organisation wants to boost up their revenue while decreasing cost by providing appropriate quality in the services. In order to attain the quality objectives, Six Sigma and Lean methodologies prove to be very effective.

The importance of implementation of quality initiatives in healthcare can be realised from the severity factor. As compared to other service sectors, the need of implementation of Lean Six Sigma in healthcare is much more important. For example, if we specially talk about pizza delivery service, there is a requirement to deliver the pizza in 30 minutes. In case, the delivery is not attempted within specified time, it can lead to loss of customer but does not cause any loss in terms of life whereas in case of healthcare, the delay of one or two minutes can make a difference in terms of life or death. Lean and Six Sigma methodologies can help healthcare industry by reducing

processing time, waiting time, cycle time, turnaround time, etc. Reduction of one or two minutes in waiting time of any activities in healthcare can make a huge impact on the lives of the patients.

This paper highlights the overview of Lean and Six Sigma applications in healthcare industry. First section deals with introduction to Six Sigma, Lean and Lean Six Sigma while Section 2 describes the methodology. Sections 3, 4 and 5 present detailed literature survey in the categories: reducing processing time, reducing variation and errors and increasing productivity respectively. The statistical analysis of all the studies is presented in Section 6, Section 7 presents the discussion on the statistical analysis and final conclusion is given in Section 8.

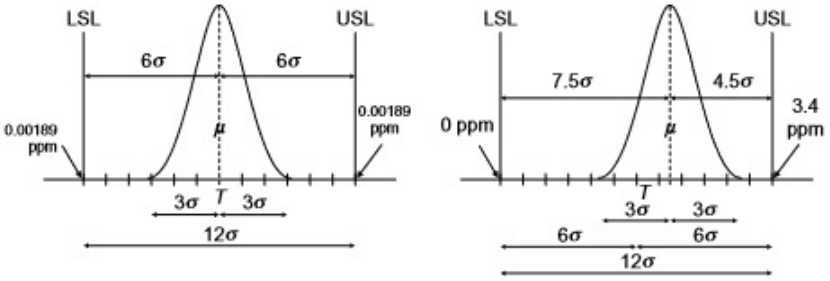
1.1 Six Sigma

Six Sigma is philosophy, methodology or approach which allows full customer satisfaction by reducing variations. The ultimate goal of Six Sigma is to raise sigma level by reducing the defects per million opportunities (DPMO) to 3.4. It is the fastest growing business management system in industry today. Many companies have saved billions of dollars by using Six Sigma in more than two decades. Six Sigma was developed by Motorola in the 1980s. It used various statistical tools like analysis of variance (ANOVA), cause and effect diagram, Pareto chart, regression analysis, etc., in order to reduce the error and variability. Snee (2010) devoted the success of Motorola to Six Sigma which helped Motorola to win 1988 Baldrige National Quality Award. According to Garza-Reyes (2015), Six Sigma gained wide popularity among organisations worldwide, with most Fortune 500 companies deploying it, since 1980.

The statistical concept behind Six Sigma is shown in Figure 1. It can be seen that the distance of both specification limit from the centre line is six standard deviations. So the process spread is equal to 12 times the standard deviation. When the process is centred at the target value, the number of defect per million opportunities (DPMO) on either side is 0.00189 which is almost negligible or defect free process. In case if there is shift in the mean from the target value due to any reasons, even then number of DPMO will not exceed 3.4. That is quite acceptable. Generally Six Sigma reduces the variability, errors and cost in such a way that number of defects will not exceed 3.4 in one million opportunities. One thing should be noted that every process does not need to operate on Six Sigma level because the level of quality varies according to its strategic and operational importance. Figure 1 shows 1.5 times standard deviation shift.

As a well-structured problem solving and continuous improvement methodology, the Six Sigma define, measure, analyse, improve and control (DMAIC) process is widely-used in problem-solving and improvement of products/processes falling below specifications. In order to measure the process performance in terms of set of critical to quality characteristics, sigma rating is used as statistical quantitative metric. The factor which differentiates the Six Sigma approach from other methods is its ability to provide bottom line results. Antony (2007) categorised the Six Sigma benefits into three generations. The first generation of Six Sigma ranges from 1987–1994 and was mainly concentrate on lowering defects. The second generation ranges from 1994–2000 and had a goal of cost reduction. The third generation ranges from 2000 onwards and focuses on customer satisfaction by creating valuable products and services.

Figure 1 Six Sigma statistical concept



Source: Given by Marques et al. (2013)

1.2 Lean

Lean originates from Toyota production system (TPS) and it focuses on increasing the speed of the process by reducing the waste of all kind by implementing standard Lean principles. The waste is defined according to Lean principles as: 'any process which does not add value to the customers'. The waste is associated with every area of business like dealing with customer, management of organisation and interaction with supplier. For example in case of hospitals, the waste may be in the form of waiting time of patients, longer turnaround time for surgery, number of pre and post complications in the surgery, lower productivity, etc. The ultimate goal of Lean is to provide the product and service through shortest route to the customer by removal of non-value added activities in between. As explained by Black and Revere (2006), Lean helps in reducing cost, increasing revenue, attracting more customer and remain competitive in the global market. Waste or non-value added activities are associated with manufacturing as well as service industry. Lean principles can readily be adopted in healthcare, banking sector, etc. to improve the efficiency and speed of the process.

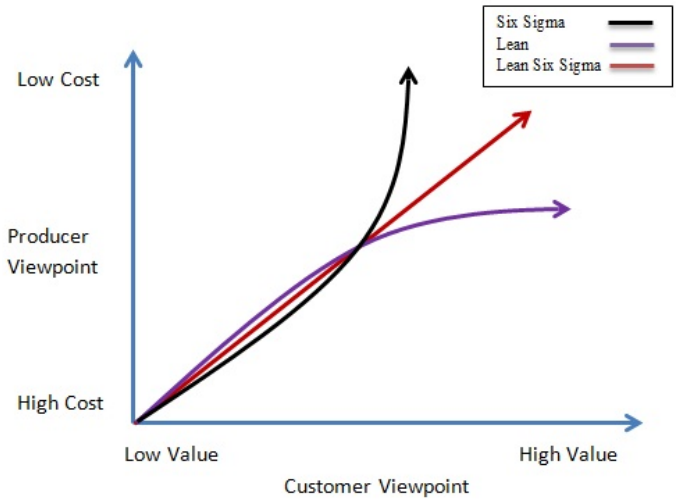
TPS identifies the seven types of waste which does not add value to the customers. These are overproduction, waiting, unnecessary transport, over processing, excessive inventory, unnecessary movement and defects. In addition to the above seven wastes, one more waste is added and that is underutilisation of skill and capabilities. In case of healthcare, the waiting time, defect and unnecessary movement types of waste are more predominate.

1.3 Lean Six Sigma

Lean and Six Sigma are two complementary methodologies in the sense that Lean focuses on reducing waste and increasing speeds whereas Six Sigma focuses on reducing error and variation and increasing consistency. So the ultimate aim of both Lean and Six Sigma is to increase customer satisfaction by reducing errors and increasing speed. How the Lean and Six Sigma are beneficial to an organisation, it can be illustrated by an example of school boy attempting his examination. In order to complete his examination in specified time, he should have good speed and second thing, he should have accuracy to make sure that he is doing things right. Speed and accuracy combined together helps the boy to get good marks. Similarly; in an organisation or in any kind of business, speed is provided by Lean by eliminating all kind of waste and accuracy or consistency is

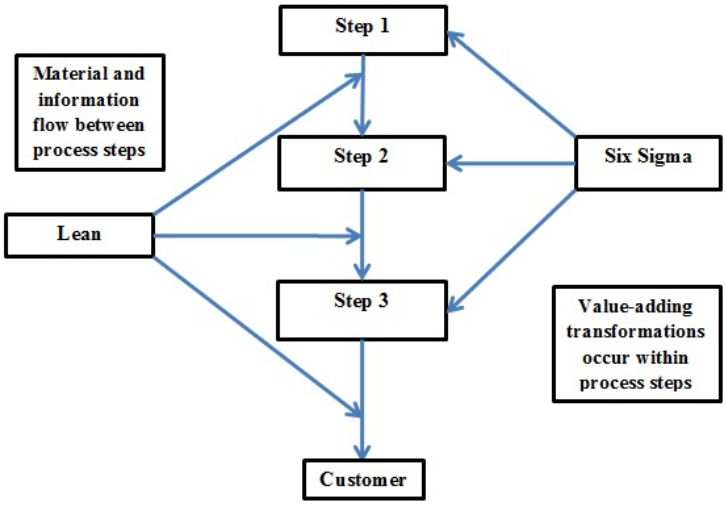
provided by Six Sigma by reducing variations and errors. So Lean and Six Sigma improve the customer satisfaction, quality, speed and maximise the shareholder value. According to Laureani and Antony (2012), these methodologies are widely adopted and used in manufacturing as well as in service organisations.

Figure 2 Relation between Lean, Six Sigma and Lean Six Sigma (see online version for colours)



Source: Given by Bakar et al. (2015)

Figure 3 Improvement opportunities between and within the box (see online version for colours)



Source: Given by Snee (2010)

The high value and low cost of products or services can be achieved by applying quality initiatives in the manufacturing and service industry. Figure 2 compares the increase in value and decrease in the cost with the use of Lean and Six Sigma separately and combined Lean and Six Sigma. It is clear from Figure 2 that both processes are

complementary to each other. In Lean, one get high value of the product or services but at the higher cost where as in Six Sigma, one get lesser value of the product or services at less cost than Lean. So combining both these factor provide higher value at lower cost.

Figure 3 shows the situations where the improvement opportunities exist and when the Lean and Six Sigma come into picture. Generally opportunities for improvement exist within the process steps (indicated by box in Figure 3) as well as between the process steps. Information and material flow occurs between the process steps and value adding transformation occurs within the boxes. The Lean comes into picture when someone has to deal with material and information flow in between the process step whereas Six Sigma is useful when one wants to improve value adding transformation within the boxes. If more actions are going on within the process steps, then process is called complex process and if more actions are going on between the process steps, the process is called simple. Figure 3 shows the improvement opportunities between and within the box as suggested by Snee (2010).

2 Methodology

The extensive research is done to find out the articles related to Lean and Six Sigma applications in healthcare. The 'Six Sigma', 'Lean', 'applications' and 'healthcare' are the key words in the search. The search excluded master and doctoral dissertation since there is greater possibilities of these studies to appear in academic and professional journals. Preliminary, 269 research papers have been screened through the reading of abstracts. After reading all these papers 115 research papers have been found suitable for this study.

The present paper deals with the overview of Lean and Six Sigma applications in healthcare sector. The further discussion is divided according to the possible outcomes of Lean and Six Sigma into following categories:

1 reduction in processing time

2 reduction in process variations and errors

3 increase in productivity.

The detailed work done by the various researchers is summarised in the following sections and subsections.

3 Reduction of processing time

This section can be further divided into following sub-categories:

1 reduction in waiting time

2 reduction in length of stay

3 reduction in turnaround time

4 reduction in cycle time.

The research done by various researchers in reducing the processing time with the use of Lean and/or Six Sigma tools is discussed in Subsections 3.1 to 3.4.

3.1 Reduction in waiting time

Cavagna et al. (2003) optimised the process of radiology reports with an objective to provide the 100% service delivery within 72 hours to outpatients and 36 hours to inpatients. This included the time from the end of examination of report to the time when it was available to the patients. Five steps Six Sigma procedure, DMAIC was applied. They found that 38% of reports were delivered beyond the specified time limit. Heuvel et al. (2006a) applied the Lean Six Sigma in the Canisius Wilhelmina Hospital to reduce longer waiting time in emergency room. After the successful deployment of Six Sigma and Lean tools, the average waiting time was decreased by 20%. King et al. (2006) redesigned the emergency department (ED) with the help of Lean thinking. All the patients were categorised into groups and it was found that all groups were spending drastically less overall time in the department. In addition to this, there was downfall in average number of patients waiting at any moment in the ED. Bush et al. (2007) significantly lowered down the waiting time from 38 to 8 days in women medical centre clinic using Six Sigma DMAIC philosophy. The total time that patients spent in a clinic was lowered down from 3.2 hours to 1.5 hours which caused the revenue increment of 73%.

Taner et al. (2007) reduced the waiting time of patients before surgery. A flow chart was prepared in order to get insight into the surgery process and cause and effect diagram was used to identify the possible root causes. The laboratory test reports and electrocardiogram availability were the main causes of waiting before surgery. Yu and Yang (2008) applied the Lean and Six Sigma approaches to reduce the registration waiting time of the patient. Six Sigma DMAIC procedures was adopted to measure and analyse the existing process and to find the root causes of the problem. The Lean standard principles help to redesign the process by cutting down non-value added activities. Arena discrete event simulation software was used to support and verify the decisions. After the implementation of solutions, suggested in 'Improve phase' of DMAIC cycle, the average waiting time was reduced to 6.55 minutes from 42.3 minutes. Jackson and Woeste (2008) used Lean Six Sigma techniques to reduce the waiting time of patients in Phlebotomy department. They found 50% reduction in waiting time; which led to increase productivity. Parks et al. (2008) implemented Lean Six Sigma to reduce the delays in trauma care and they were successful in reducing trauma resuscitation units dwell time by one hour per patient.

Mandahawi et al. (2010) reduced ED waiting time with the help of design for Six Sigma and discrete event simulation software. Design for Six Sigma design, measure, analyse, design and verify (DMADV) procedure was used to develop the triage process for ED. The ProModel software was used to develop a discrete event simulation model to verify the designed model. As a result of this, waiting time and length of stay was decreased by 61% and 34% respectively. In terms of sigma level the waiting time and length of stay sigma level jumped to 5.18 and 3.09 from 0.66 and 0.58 respectively. Sedlack (2010) utilised the Six Sigma as well as statistical process control techniques in order to reduce the surgeon waiting time between the cases and length of stay after colon surgery. The average waiting time of surgeon between the cases was reduced to

53 minutes and average length of stay to 10 days, after utilising the Six Sigma DMAIC procedure and process control chart. The author suggested various process control mechanisms to improve these surgical processes.

Faiomy and Shabana (2012) shortened the waiting time entering to vaccination room. Initially the average waiting time was 25.4 minutes but after applying Six Sigma initiatives, it was decreased to 7.55 minutes. Gijo and Antony (2013) made use of Lean Six Sigma methodology in order to lower down the patient waiting time in outpatient department. The various tools employed were cause and effect diagram, box-cox transformation, control chart, Kruskal wallis test, etc. As a result of this project, the average waiting time fell from 57 minutes to 24.5 minutes and standard deviation to 9.27 minutes from 31.15 minutes; which caused increased patient satisfaction and faster recovery of patients. Gijo et al. (2013) utilised the Lean and Six Sigma tools to reduce waiting time of patient in pathology department of a multispecialty hospital. In this case study, the pathology department had three major activities, i.e., sample collection, testing and preparation of reports. The focus of the project was to reduce waiting time for sample collection process. Six Sigma DMAIC model was adopted to reduce average waiting time and standard deviation of sample collection process. The various tools such as cause and effect diagram, box plot, dot plot and hypothesis test were used to analyse the data with the help of Minitab. As a result of this project, it was found that average waiting time of the patient decreased to 11 minutes from 24 minutes and standard deviation reduced to 10.04 minutes from 17.5 minutes.

Dinesh et al. (2013) used the Six Sigma approach in order to reduce the waiting time in the outpatient cardiology office in India. DMAIC process was adopted for the case study and various improvements were suggested and implemented in the 'Improve phase' of DMAIC process like opening of new registration counter, modification of registration form, appoint new staff to handle telephonic calls, etc. various tools like hypothesis test, cause and effect diagram, etc., are utilised. In addition to reducing waiting time, there was additional benefit of reducing the waiting time for the lab reports. Chan et al. (2014) improved the patient flow in an ED with the application of Lean techniques. They identified the various non-value added activities and modify the existing system. Lean thinking allowed using priority admission triage program, enhanced communication, etc. The critical to quality characteristics selected for the case study was admission and blood result waiting time. The authors claimed that admission waiting time was reduced to 24.45 minutes from 54.76 minutes.

Arafeh et al. (2014) applied Six Sigma to decrease the patient waiting time in outpatient pharmacy, located in cancer treatment hospital. As a decision supporting tool, discrete event simulation model and design of experiments were implemented. Various improvement opportunities are identified and implemented to reduce the waiting time. After the project, the waiting time of patients decreased by 50%. Ligher et al. (2014) utilised Six Sigma in Akron children's hospital and there was 90% decrease in waiting time for MRI in the radiology department. This increases the opportunities of more number of MRIs of patients with increased revenue. Berlanga and Husby (2016) also made use of Six Sigma and Lean principles to shorten the Emergency waiting time in Texas Medical Centre. There was significant improvement in terms of average time of emergency doctors to see patient, door to balloon time for heart attack patients, etc.

3.2 Reduction in length of stay

Heuvel et al. (2004) implemented the Six Sigma technique to reduce the length of stay (LOS) of gynaecology patients. These patients had to undergo an abdominal uterus extirpation (AUE). The existing LOS was estimated to be 7 days with standard deviation of 2 days. Various improvements like preparation of clinic, and home caring, etc., were recommended by the authors. After the advancement in the current process, the LOS reduced to 5.2 days and standard deviation to 0.9 days. The expected cost saving form this project is around $57,800. Heuvel et al. (2005) reduced the LOS of chronic obstructive pulmonary disease in Red Cross Hospital; Netherlands. Due to lesser number of beds in the pulmonary department, patient had to shift to internal medicine department. Statistical analysis was performed and it was found that there is significant difference between the admission times of two departments. Pulmonary department has two days lesser LOS and it is not attributed to patients and physicians characteristics. The authors finally rebalanced the bed capacity so that patients can be admitted to pulmonary department only. It helped in reducing the LOS and more admissions in pulmonary department which caused annual saving of $40,000.

Heuvel et al. (2005) reduced the LOS in children department also. The authors identified that there was significant decrease in LOS when patients were allowed to stay with their admitted children during night. It also caused annual saving of $30,000. Christianson et al. (2005) called for Six Sigma in order to decrease the LOS for admissions to orthopaedics department. Heuvel et al. (2006b) reduced the LOS in delivery room after the delivery because the hospital was facing the problem of insufficient delivery room. In order to decrease the LOS, the authors designed new procedures and protocols. After implementation of these measures, the hospital reduced its average LOS to 3.4 hours form 11.9 hours which resulted in annual saving of $68,000. Dickson et al. (2009) applied the Lean techniques in the ED of hospital to reduce LOS. The patients and staff satisfaction, expense per patient, LOS and patient volume were compared before and after the implementation of Lean techniques. Even the patient visit increased by 9.23%, but there was slightly decreased in LOS. That is the beauty of Lean techniques.

Taner et al. (2007) discussed the case study of reducing LOS in one hospital of Turkey that was following faulty discharge planning process. It was found that there were many patients waiting to get placed in room due to longer LOS of admitted patients. Cause and effect diagram was prepared for faulty discharge planning process and there were excessive improvements in terms of decreasing LOS. Anguelov et al. (2008) improved the patient flow in the ED over two years using Lean thinking. After two years, the LOS decreased by 3% regardless of 18% increase in patient volume and 22% increase in patient admission per month. In addition to this, there were additional benefits of 9% decrease in direct expenses and 9% increase in patient satisfaction too. The author concluded that there is great ability of Lean to absorb the increase in work load without increase in patient length of stay. Sagy (2009) utilised the Six Sigma methodology to reduce the LOS of patients requiring tracheostomy and gastrostomy tube placements before transfer to rehabilitation facilities. In this project, he could not do any improvement in terms of downfall in time transfer to rehabilitation facilities.

Bisgaard and Does (2009) reduced the LOS using five steps DMAIC procedure of Six Sigma. The tools utilised were: dot plot, Pareto analysis, normal probability plot, box plot, ANOVA, Control charts, etc. Due to this, average LOS decreased by 2.4 days for patient volume of 30 per year and caused annual cost saving of $36,000. Albert et al. (2010) took advantage of Six Sigma philosophy to reduce the ambulatory surgery LOS and the project team was able to achieve shortening of 30 minutes in LOS. Niemeijer et al. (2010) implemented Lean Six Sigma techniques to improve the discharging procedure in trauma nursing department, Netherlands. The critical to quality characteristics selected for the study was length of stay; which was observed as 10.4 days. The authors applied the 'Dutch appropriateness evaluation protocols' in order to find the root causes of longer length of stay. After implementation of suggested improvements, the average LOS was reduced to 8.5 days.

Allen et al. (2010) improved the US hospital discharge process with Six Sigma DMAIC approach. Numerous tools were utilised in different phases of the Six Sigma like Pareto chart, cause and effect diagram, statistical process control, etc. The authors suggested focusing on physician preparation and after considering this suggestion, the average discharge time was reduced to 2.8 hours from 3.3 hours. In addition to this improvement, there was additional benefit of reducing the missing chart data by 62%. Mandahawi et al. (2011) applied the Lean Six Sigma tools to reduce the LOS for Ophthalmology day case surgery. The various non-value added activities were removed with the application of Lean thinking, i.e., value stream mapping, supplier input process output customer (SIPOC), etc. and various improvements were suggested in the 'Improve phase' of DMAIC process. The authors found 48% reduction in patients' LOS period.

Niemeijer et al. (2012a) reduced the LOS for hip fracture. The various variables effecting LOS was discovered and new suggestions were incorporated in order to redesign the process pathway. As a result, there was reduction of LOS by 4.2 days and average duration of surgery by 57 minutes. Niemeijer et al. (2012c) lowered down the LOS despite the increase in number of patients in University Medical Centre, Groningen. After implementing quality initiatives, LOS was less than 9 days which was 10.5 days in the beginning. A furthermore, inappropriate hospital stay decreased from 30 to 10%. Improta et al. (2015) utilised the Lean Six Sigma approach for the reduction of LOS in Prosthetic hip replacement surgery. As a result of this project, the average LOS was reduced from 18.9 days to 10.6 days.

3.3 Reduction in turnaround time

Adams et al. (2004) practiced Six Sigma initiatives to reduce the turnaround time (TAT) between the surgery cases. The sigma level was increased from 1.53 to 2.13 and mean time was decreased from 22.8 minutes to 15.6 minutes. Similarly; the standard deviation (SD) was reduced from 16.3 minutes to 13.9 minutes. Gelrud et al. (2008) addressed the problem of longer TAT in ED. There was 20.4% reduction in TAT for non-admitted patients; which would lead to increase patient satisfaction. Raghavan et al. (2010) shortened the patient TAT in Cardiac-Catheterisation Lab of USA community hospital with the applications of Lean Six Sigma technique. The numerous sources of errors were identified that lead to lengthened TAT. Discrete event simulation (DES) software Arena helped to know the what-if questions about the improvements suggested by Lean and Six Sigma techniques. Simulation results showed 44.5% reduction in TAT.

Bhat and Jnanesh (2013) enhanced the performances of health record preparation process in Health Information department, India. The critical to quality characteristics selected for the study was TAT. Due to longer TAT, a lot of in-process inventory at the end of each day was accumulated. Five steps DMAIC procedure was applied along with Lean standard principals. As a result of the project, the TAT of the project decreased to 39 minutes from 52 minutes and SD was reduced to 0.43 from 2.33 per 10 health records batch. The sigma level rose to 6 which were earlier at 0 levels. Sanders and Karr (2015) reduced the TAT of ED specimen with the utilisation of Lean Six Sigma approach. The whole process of specimen moving from ED to lab is thoroughly investigated and possible improvements were suggested and implemented. The results showed that there was 50% reduction in the vials used for testing, 50% decrease in unused specimen and 30% decrease in complete blood count analysis median TAT.

Basta et al. (2016) utilised the combined Lean and Six Sigma approach in order to decrease the dispatch time of medical reports. Structured Six Sigma approach along with standard Lean principles was used to increase the number of reports dispatched on patient's visit. After implementation, it was found that 90.6% of the reports were dispatched on the day of patient visit, initially this was 12.3%. This helped to lower down the TAT for report preparation.

3.4 Reduction in cycle time

Bahensky et al. (2005) reduced the cycle time for CT scanning by Lean Six Sigma approaches. For this project, a team of 15 members worked for 5 days for the identification and removal of non-value added activities in the concerned department. After implementing the changes, it was found that cycle time was decreased drastically in the sense that there is capacity to handle 3,000 additional CT scanning cases. It caused revenue increasing by $750,000. Christianson et al. (2005) used Six Sigma technique to reduce cycle time in ED in the US. The cycle time is the time between patients' arrivals to discharge. The project team was able to push down the cycle time to 120 minutes form 162 minutes. He also reduced patient preparation cycle time by 3 minutes and 20 seconds and variation by 5 minutes 14 seconds.

Parker et al. (2007) improved the cycle timing of antibiotic prophylaxis with the target of less than 60 minutes before incision. After implementation of Six Sigma methodology, there were drastically improvements with 86% of patients receiving their antibiotic prophylaxis with in the specified time frame. Sagy (2009) reduced the time from order to insertion of peripherally inserted central catheters. After one month, the mean time improved from 3.7 ± 2.7 days to 2.42 ± 1.6 days and to 1.7 ± 1.2 days at the end of one year. Al-Araidah et al. (2010) cut down the lead time at the inpatient pharmacy of a Jordan's hospital. To attain this purpose, the author used the Six Sigma DMAIC approach and 5S principles to identify and reduce the waste. After the 'Improve phase', there was more than 45% reduction in drug dispensing cycle time. Yeh et al. (2011) applied the Lean Six Sigma tools to minimise the cycle time of door to balloon process of acute myocardial infraction. The cause and effect diagram was employed to determine the root causes of the problem in addition to the Lean thinking which focus on reducing non value added activities. It was found that cycle time of the process decreased by 58.4% which is even less than the ACC standards. In addition to this, average days of hospital stay decreased by 3 days and process cycle efficiency increased to 51.81% from

32.27%. They claimed that this project was also helpful for cost saving of $ 4.422 million in medical resources.

Celano et al. (2012) provided a new roadmap by linking Lean Six Sigma with simulation. This roadmap is applied in different departments and positive results are obtained. The mean flow time of patients admitted to audiology and cardiology, was reduced by 50% and 25% respectively. For medicine department, the expected flow time increased by 13.2%. Bhat et al. (2014) utilised the Lean Six Sigma to reduce the registration process cycle time in health information department of a medical college hospital in India. DMAIC approach was adopted in the study. The results showed that cycle time of the process decreased to 1.5 minute form 3 minute and SD was reduced to 21.2 seconds form 61 seconds. They also applied DES software (Rockwell Arena) as decision supporting tool. From the simulation; it was found that there is 94% reduction in patient waiting time, 91% reduction in queue length and 48% increase in scheduled utilisation of staff.

Bhat and Jnanesh (2014) adopted the Lean Six Sigma tools in rural hospital to diminish the cycle time of outpatient department services. In order to measure and analyse the current performance, statistical technique as well as Gemba methods were used. To improve the process, Lean tools like Kanban, 5S, Ergonomic design, etc. were used. The authors ended up with results that the cycle time of the process reduced from 4.27 minutes to 1.5 minutes. In addition to this result, there was supplementary result of 97% loss of average waiting time and 91% shrinkage of queue length. El-Eid et al. (2015) lowered down the discharge time consists of discharge orders to patient actually leave the room using Six Sigma DMAIC philosophy. There was 22.7% decrease in discharger time, i.e. from 2.2 hours to 1.7 hours. There was bit change in patient LOS fallen from 3.4 to 3.1 days. Barrios and Jiménez (2016) applied Six Sigma methodology to shorten the appointment lead time in Obstetrics outpatient department of maternal child hospital in Colombia. Appropriate Six Sigma DMAIC approach along with SIPOC, cause and effect diagram and correlation analysis was adopted. The project caused reduction in lead time from 6.89 days to 4.08 days and SD fell from 1.57 days to 1.24 days.

Time is always an important parameter for every kind of business. It has got special importance in healthcare because due to delay, longer waiting time or longer cycle time, someone has to pay heavy penalty in the form of his life. So reducing the processing time by even 1 to 2 minutes can save too many lives. That's why; Lean and Six Sigma can play a critical role in healthcare sector. But reducing the waiting time, cycle time and LOS should not affect the quality of process because our ultimate aim is to increase the quality. So the time should not be reduced at the cost of quality.

4 Reduction in process variations and errors

Jean and Sridhar (2001) claimed to shorten the process variability in the radiology department of the US with Six Sigma approach. There was 90% declined in the errors of ordering process and cost saving of $800,000. Johnstone et al. (2003) used the Six Sigma in Naval Medical Centre, US to investigate the errors for various processes such as Pharmacy, Radiology, Blood bank, etc. within ancillary services. These errors were translated into defects per million opportunity (DPMO) and Sigma rating. It was concluded that Six Sigma is acceptable metric for some aspect of ancillary services. Chan (2004) took the project to compress the dispensing errors in pharmacy of outpatient clinic

because the pharmacy dispensing errors ranked second in list of errors in Taiwan. As a result of the project, dispensing errors mean value reduced from 335 errors per million to 200 in three years.

Condel et al. (2004) applied Lean production methods in order to make Pathology department error free. The author's objective was to provide the more accurate diagnostic information to the patients in efficient manner. Standard Lean principles were adopted along with 5S which caused the process to be streamlined by removal of non-value added activities. At the end, chances of making the errors were significantly reduced as compared with previous practices. Guinane and Davis (2004) implemented Six Sigma to reduce the groin injuries in US hospital. In the starting, the groin injuries were 41,666 DPMO and this caused sigma level of 3.23. Previously, the average cost per case was $7,589 and average LOS was 2.54 days for patients not experiencing groin injuries. On the other hand, when groin injury occurred, cost increased to $11,298 with LOS of 3.98 days. After the successful implementation of Six Sigma DMAIC, the DPMO lowered to 8,849.5 caused sigma level improvement to 3.87. Pexton and Young (2004) reduced the surgical site infections using Six Sigma philosophy. Several solutions were suggested in 'Improve phase' of DMAIC process which caused the process Sigma level to rise from 0 to 2.68 level and annual saving of $ 1 million. Simmons-Trau et al. (2004) used Six Sigma to shorten the ventilator associated pneumonia (VAP). The project was implemented in surgical intensive care unit (SICU) and house wide intensive care units. After intervention, there was 54% downfall in VAP in SICU and 33% reduction in house wide intensive care unit per 1000 ventilator days. Sunyog (2004) applied Lean and Six Sigma in US hospital clinical laboratory to eliminate the waste systematically and minimise the variation. After implementation of DMAIC, reduction in overtime spending by 60% and annual saving of $ 400,000 in the first year was observed.

Riebling and Tria (2005) applied the Six Sigma DMAIC approach to reduce the errors in automated lab of US. The project team reduced the analytical errors by 35% and attained a Sigma score of 5. Chen et al. (2005) made use of Six Sigma to turn down the defect ratio of films in the radiology department. In 'Analyse phase' of DMAIC cycle, it was observed that DPMO were 55,197 and after making improvements in the 'Improve phase', DPMO reduced to 35,319. Jimmerson et al. (2005) lowered down the waste as well as errors; using TPS. During the project, several problems were identified which led to rise in errors. Lean systematically reduced errors and led to increase customer satisfaction. Castle et al. (2005) utilised the Six Sigma methodology to shorten the medication errors of home delivery service in pharmacy department in US. Six Sigma DMAIC process was followed to eliminate the root causes and suggested the possible improvements. As a result, there was 33%, 49% and 69% declined in wrong drug selection, wrong direction and sound alike/look alike errors respectively. Frankel et al. (2005) lowered down the incidence of catheter related bloodstream infections (CR-BSI) in SICU. Before implementation, there was CR-BSI rate of 11 per 1000 catheter days and after implementation, the CR-BSI rate was 1.7/1000 catheter days. There was a tremendous improvement of 650% in reducing infections.

Heuvel et al. (2005) applied the Lean Six Sigma approach to reduce the errors in the invoice from agencies. The authors found that there was significant numbers of errors which were in the favour of agencies. They established and implemented the declaration form for agencies which caused annual saving of $75,000. The important stat is that hospital had one time saving of $35,000 due to refund from temp agencies. Heuvel et al.

(2005) in another project reduced the number of errors in invoices issued to patient and insurance companies. A large number of improvement points were implemented which cause errors to decrease from 9% to less than 1% and annual saving of $200,000. Esimai (2005) brought into play Six Sigma to lower down medication errors. There was significant reduction in dose error, duplicate order, drug error, etc. There was also a downfall in the order entry errors. Koning et al. (2006) lowered down the number of mistakes in the invoices. Preliminary study showed that only 15% of the invoices are correct and author's aim is reduce the errors by 100%. A number of factors influencing the errors in the invoices were found out and possible improvements were suggested which caused reduced rework and cost savings. Raab et al. (2006a) stepped down thyroid gland fine-needle aspiration error using Lean techniques. As a result of implementation of standard Lean principles, there was decrease in false negative rate from 41.8% to 19.1%, the non-diagnostic rate of specimen increased from 5.8% to 19.8% and the sensitivity increased from 70.8 to 90.2%. Raab et al. (2006b) focused on reducing the medical errors by improving Papanicolaou test quality with the help of TPS. After the intervention, the frequency of errors per correlating cytologic-histologic specimen pair decreased from 9.52% to 7.84%. In addition, the percentage of Papanicolaou test with a diagnosis of typical squamous cells of undetermined significance decreased from 7.8% to 3.9%.

Shannon et al. (2006) utilised the TPS to eliminate the central line infections in America because every year; 2, 00,000 Americans died due to central line–associated bloodstream infections (CLABs) with 15-20% mortality. After implementation, within a year there was decrease in CLABs from 49 to 6 and mortalities from 19 to 1 despite increase in central lines and number of line days. Lloyd and Holsenback (2006) applied Six Sigma in Radiology Department of Commonwealth Health Corporation, US. There were astounding results like 90% reduction MRI ordering process errors, radiology cost per procedure decreased by 21.5% and annual cost saving of $1.65 million. Taner et al. (2007) made use of Six Sigma in order to reduce the catheter infections after surgery. Cause and effect diagram was prepared to find possible root causes of the problem identified. In the end, master plan was developed which gave education to the caregiver. Taner et al. (2007) applied the Six Sigma to increase the magnetic resonance imaging (MRI) quality. There is always risk of variations in diagnostic imaging process and these variations are more prone from observer to observer. A cause and effect diagram was prepared to find the possible causes. The difference in observer's performance was overcome by proper training. Similarly other remedial actions were taken to improve MRI image quality.

Drenckpohl et al. (2007) utilised Six Sigma methodology in order to reduce errors in breast milk administration. The authors discussed the possible hazard due to inappropriate administration of breast milk. At the end, errors were reduced to less than 3.4 defects per million opportunities. Furman and Caplan (2007) reduced the error in Virginia Mason Medical Centre, US by using Lean approach. The authors adopted the patient safety alert (PSA) system, according to which if any activity of employees caused harm to patients, then that activity immediately stopped until the problem is resolved. As a result, the 6,112 PSA reports were received in December 2006 form manager, physicians, nurses, etc. Another surprising stat was that the average number of reports per month was 3 in 2002 and rose to 285 per month in 2006. Pan et al. (2008) applied the Six Sigma and health quality improvement circle approach to reduce the unplanned

endotracheal extubation (UEE). The result showed that UEE event decreased to 4.1% from 11.3% and standard errors improved to 3.2σ form 2.7σ.

Kumar and Steinebach (2008) reduced the medical errors in surgery process of US hospital. Errors involved pain, complications, etc. DMAIC process of Six Sigma was employed and it was observed that there were 6210 medical errors per million tasks. With the help of cause and effect diagram, root causes were identified and various Poka-Yokes were suggested which caused the surgery to perform without pain and complications. Sagy (2009) took advantage of Six Sigma philosophy to provide downfall in medication order defects. The average numbers of defects per order were reduced from 2.1 to 1.4. Dupree et al. (2009) used the Six Sigma DMAIC approach for the pain management of two inpatients unit in the urban academic medical centre. The project team was able to raise overall satisfaction excellent rating for pain management from 37% to 54%.

Taner (2013) applied the Six Sigma methodology to lower down the intraoperative and postoperative complications in cataract surgery of Turkish public hospital. Cause and effect diagram, process mapping, failure mode and effect analysis, control chart, process capabilities, etc. were utilised to address the root causes of the problem. The wrong IOL placement, low quality of IOL and inefficient skill of surgeon were the root causes of the problem. After addressing the root causes, the Sigma level was increased from 2.60 to 3.75. Elbireer et al. (2013) reduced the errors in laboratory data entry using Six Sigma approaches. Initially; there were 423 errors per month which were lowered down to 166 errors per month at the end of 12 months. It caused annual saving of $50,115. Taner et al. (2013) applied Six Sigma to reduce the number of complications occurred during coronary stent insertion process. Six Sigma DMAIC model was suggested for insertion process. The root causes were identified as inexperience of staff, inappropriate selection of stent type, inappropriate selection of balloon type, etc.

Lighter et al. (2014) lowered down the medication and fluid administration errors in the weight determination of paediatric burn patients. Ramaswamy et al. (2015) lowered the average residual spherical errors for the improvement in postoperative visual outcome following cataract surgeries using Lean Six Sigma approach. The average residual spherical errors reduced to 0.25D from 0.36D in one year. It caused increased in financial accrual from 11.5 crores to 13.5 crores. Kuwaiti (2016) applied the Six Sigma DMAIC process to reduce the medical errors in the Outpatient Pharmacy in Saudi Arabia. As a result of this project, DPMO decreased from 56,000 to 5,000 and Sigma rating improved to 4.08 from 3.09. Bertolaccini et al. (2015) utilised the Lean Six Sigma methodologies in order to reduce the complications during and after lobectomies. Celik et al. (2016) used the Six Sigma approach in order to lower down the inoperability among lung cancer patients. The root causes of the problem were identified using cause and effect diagram, failure mode and effect analysis, SIPOC, etc. After finding the root causes, solutions were implemented in 'Improve phase' of DMAIC model and positive results were obtained. Baril et al. (2016) made use of Lean approach along with Kaizen and DES to reduce the patient delays in receiving their treatment. It was found that patient delays were reduced by 74% after 19 week of implementation. Gheysari et al. (2016) reduced the cancellation of surgery using Lean Six Sigma approach. After implementation, there was significant downfall in cancellation of surgery, i.e. from 31 cases to 12. Montella et al. (2017) lowered down the number of patients affected by sentinel bacterial infections using Lean Six Sigma methodology and there were significantly good results.

Healthcare is involved with more human activities which make them prone to errors and rework. If we talk about manufacturing industry, then error can cause rework and at the longest, can cause the work piece to be scraped. But in healthcare, a small error can cause someone to leave his life. US Institute of Medicine (IOM) issued several reports which clearly highlighted the importance of building safe and effective healthcare system. In one of its report, released in November 1999 by US Govt., the authors estimated that around 98,000 patients die each year due to medical errors. Annual seminars NATHEALTH (2017) organised by Healthcare Federation of India reported that 16% of global share of maternal deaths and 27% of global new born deaths still accounts by India and the 60% of death in India is due to non-communicable diseases. All these reports call for quality healthcare system which needs quality initiatives like Lean and Six Sigma to be applied.

5 Increase in productivity

Kooy et al. (2002) implemented Six Sigma to improve the safety and efficiency of acute anticoagulation with heparin. Six Sigma DMAIC model was utilised and there was significant reduction in number of steps in medication administration which would certainly improve the patient satisfaction and staff productivity. Sehwail and DeYong (2003) improved the patient and physician satisfaction using Six Sigma in US' Mount Carmel health system. The project caused financial return of $3.1 million and ultimately increased in productivity. Heuvel et al. (2004) employed Six Sigma approaches in order to reduce the preparation time for intravenous medication. Mean preparation time for the one dose of intravenous medication revealed to be 165 seconds and SD to be 50 seconds. Various changes were made in the current process like in the workload and number of injections to be prepared, etc. Due to which, the mean time reduced to 104 seconds and SD to 12 seconds. The annual cost saving from the project was $33,600. Elberfeld et al. (2004) improved the quality of patient care in Acute myocardial infraction (AMI) and Congestive heart failure (CHF) using Six Sigma philosophy. The project met the quality standards benchmarked both external and internal.

Christianson et al. (2005) increased the rate of patient encounter that are free from medication related harm from 80% to 98% which caused Sigma level to rise to 3.5 from 2.3 with Six Sigma. Chan et al. (2005) maximised the magnetic resonance imaging (MRI) capacity using Six Sigma methodology. There found 18% increase in patient throughput for MRI examinations. Kang et al. (2005) used the Six Sigma approach to improve the quality of picture archiving and communication system (PACS) and to reduce the resource required for its management. As a result of the project, the overall resource requirements were improved to 79% of the previous requirements. Heuvel et al. (2006b) optimised the use of operating rooms (ORs) with just simple steps to increase the productivity. The authors aim was to open the ORs on time and made use of all the available facilities. With application of Six Sigma data driven approach, the hospital was able to start the ORs 9 minutes earlier. It seemed to be small improvement but this improvement applied to eight ORs which allowed additional 400 patients to handle with cost saving of $273,000 without any additional resources.

Heuvel et al. (2006b) claimed to reduce the number of patients receiving Intravenous Antibiotics (IV) by switching to oral administration. A number of improvements were implemented such as development of new protocols contains switching criteria,

automatic alert to evaluate the medication, etc. After this project, the number of patient receiving IV reduced to 157 from 291; caused annual saving of $75,000. Peltokorpi and Kujala (2006) correlated the work in progress concept with patient in process and along with DMAIC approach applied it to hip replacement case study. They found that the approach not only provide total cost of patient episode but also improves the patient in-process efficiency. Carrigan and Kujawa (2006) discussed the Six Sigma applications in improving the emergency medical services billing accuracy. At the time of initiation of project, Sigma level of billing accuracy was 2.7 and it was raised to 4.25 at the end of the project. It led to annual saving of $274,000. Koning et al. (2006) optimised the operating theatre utilisation through Six Sigma methodology. The author's main focus was on starting time. The actual starting time was 8:00 am; whereas the data showed the average start time 8:35 am. Possible reasons and solutions were found out for the delay in starting and substantial improvements were achieved.

Eldridge et al. (2006) used the Six Sigma process in four intensive care unit (ICU) of US to implement the centre for disease control and prevention (CDC) guidelines for hand hygiene. CDC focuses on alcohol based hand rubs (ABHR) instead of soap and water. As a result, observed compliance increased from 47% to 80% based on 4000 observations. In addition to this, mass of ABHR used per 100 patient days were increased by 97%, 94% and 70% in three intensive care units. Taner et al. (2007) reduced the unnecessary laboratory test in Paediatric and obstetrics gynaecology wards. Flow chart of the process and cause and effect diagram were used to find possible root causes. Finally, there was development of standards for sample collection, sample transport and reports preparation. Jushuf and Griffiths (2007) lowered down the follow up and increased the capacity of genitourinary (GU) medicine services in UK. They discussed three case studies with more than 30% reduction in follow up in all. Fairbanks (2007) improved the operating room (OR) throughput with the use of Lean and Six Sigma. There was drastically improvement in patient flow and team work. The patient satisfaction survey also demonstrated increase in patient satisfaction and better communication. Gorman et al. (2007) used the Six Sigma DMAIC model to improve the documentation and communication radiology preliminary and final reports.

Kim et al. (2007) improved the quality of patient care with bone and brain metastases using Lean thinking. The team reduced the number of individual steps to start treatment to 16 from 27. After the intervention, the number of patients receiving consultation, simulation and treatment increased from 43% to 95% with in the same day. Ben-Tovim et al. (2007) used the Lean thinking to redesign the care at Flinders Medical Centre in Australia. After the intervention, there was significant improvement in the hospital in terms of safe and accessible care. It also improved the flow of patients through the clinical and other system in ED as average time spent in the department reduces by 48 minutes in first year of implementation. Jin et al. (2008) designed and operated a healthcare logistic centre using Six Sigma and Lean approach. The authors suggested 11 solutions in 'Improve phase' of DMAIC model which caused better utilisation of space, better store management, timely delivery of right items at right place, etc. The project benefited the organisation with annual saving of $800,000. Neri et al. (2008) utilised the Six Sigma approach to control the utilisation of blood product. After the utilisation, there was reduction in inappropriate transfusions of packed red blood cell to 5% from 16%, increased communication between laboratory and clinic, etc.

Khurma et al. (2008) improved the patients experience in their hospital stay at ED using Lean approach. Simulation based models were developed to compare the current and future state. The various standard principles were introduced and there was huge increase in efficiency and decrease in cost of proposed model. Taner and Sezen (2009) utilised the Six Sigma to reduce the turnover intentions of doctor in medical emergency services. The tools employed were: factor analysis, multiple regression, analysis of variance (ANOVA) and gage repeatability and reproducibility. The personal stress level and salary were the root causes for high turnover intensions. The rolled throughput yield of the process increased to 78% and net revenue increased by $0.84 million on annual basis. Lent et al. (2009) used the Lean approach to improve the efficiency of Chemotherapy day unit. There was 24% growth of treatment and bed utilisation, staff productivity increases by 12% and 81% reduction of over time. Wijma et al. (2009) improved the efficiency of nursing department in Netherlands using Lean Six Sigma approach. The project resulted in decrease in annual cost by €147,000.

Fischman (2010) used the Lean Six Sigma methodologies in internal medicine residency clinic of US to improve patient-physician familiarity, work flow process and continuity of care. Rapid cycle tests, time study, statistical methods along with Minitab were employed for the measurement and analysis. There was significant increment in terms of critical to quality characteristics selected. Yamamoto et al. (2010) utilised the Six Sigma to improve the productivity of inpatient insulin administration affected by the meals delivery and radiology test. After the implementation, 98% of meals were delivered on time and around 90% to 95% patients were adequately identified for treating with insulin. Kumar and Thomas (2010) proposed a process flow model for diagnosis and treatment of chest pain using Six Sigma DMAIC and evidence based medicine to increase the productivity and throughput. Pocha (2010) reduced the number of portable chest X-rays in emergency room and there was reduction in X-rays from 32% to 23%.

Cima et al. (2011) improved the efficiency of operating room, using Lean and Six Sigma in Academic Medical Centre of US. The project resulted significant improvements in on-time starts and downfall in number of cases after 5 P.M. LaGanga (2011) used the Lean thinking to increase the capacity of outpatient clinic. As a result, there was 27% increase in service capacity and 12% reduction in no show case. Niemeijer et al. (2012c) lowered down the unnecessary diagnostic test for trauma patient with Six Sigma. After the project, the average number of diagnostic test per treatment reduced by 30.4% despite the large number of patients and caused annual saving of €52,360. They reduced the cost of implants and equipments, used by the surgeons for their surgery. This involved stronger management commitment which allowed to change the equipment despite the interest and comfortless of surgeon. They also increased the productivity by reducing the material usage in trauma ward such as dressing, injection syringes, etc. in another project. In this project, they claimed that average cost per patient decreased from €44 to €39.

Southard et al. (2012) utilised the radio frequency identification (RFID) in healthcare along with Six Sigma DMAIC and DES. Their purpose was to improve the effectiveness and efficiency of outpatient surgical process. Several Poka-Yoke techniques were applied and proved to be beneficial in the project. For DES, 'Rockwell Arena' simulation software was used in decision making. The study provided annual cost saving with RFID implementation of $1.93 million. The average cost saving per patient was $298 and time saving per patient was 1.1 hours. Taner et al. (2012) improved the work flow in diagnostic imaging process using Six Sigma. The root causes of the problem were found out to be improper positioning of patient and malfunction of PACS system. After

recommending changes, the process Sigma level was increased to 4.2 from 3.5. Silva et al. (2012) used the Lean Six Sigma approach to improve the inventory quality control in clinical engineering. The project raised the inventory quality from 62.6% to 99.4%, i.e., astounding effect of Lean Six Sigma approach. Chiarini (2012) applied the Lean and Six Sigma approach to increase the safety of staff and nurses, who manage the cancer drugs. The author performed failure mode and effect analysis (FMEA) and showed improvement in safety and health of nurses and staff. Additional benefit was the reduction of cost due to minimisation of non-value added activities.

Smith et al. (2012) applied Lean thinking along with Kaizen theory in public health practice. The project resulted in reduced operational cost, improved working conditions; reduced nursing cost by 12% and 4% growth in number of patients served with same level of staff. Niemeijer et al. (2012b) used Lean Six Sigma approach for declining in overuse of diagnostic test for trauma patients in Netherlands. After the intervention, there was average reduction in diagnostic test by 16%. Sarkar et al. (2014) specially outlined the importance of 'Control phase' of DMAIC procedure of Six Sigma. Initially 90% of medical test completed within a period of seven days which was raised to 98% after implementation of suggestions and proper control of that improvements. Nayar et al. (2016) used Lean Six Sigma approach to develop recommendations and implement effective process in medication management of dual care veteran patients. Kutsal et al. (2017) improved the productivity of histopathology laboratory using Six Sigma. This project caused the increase in Six Sigma score from 24% to 68% for all phases.

Increased productivity can be obtained by reducing the processing time and variations. It causes increase in revenue, decrease in operating cost, rise in throughput and capacity, downfall in overuse of resources, etc. in healthcare sector. Basically, when all the errors, variations and processing time are minimised to possible extent, one can think about increase the productivity and throughput. On the basis of presented literature; it can be concluded that the Lean and Six Sigma play a critical role in raising productivity of healthcare sector.

6 Statistical analysis of studies

As indicated earlier, 115 suitable research papers were identified for this study. Generally the statistical analysis can be defined as collection, examination and interpretation of quantitative data in order to find trends, relationships and underlying causes. The bar chart, pie chart, Pareto chart and Matrix plots are used for the statistical analysis. Analysis of studies are categorised into following subsections.

6.1 Analysis of studies using bar and pie charts

The bar chart is plotted on number of studies done in different years and focuses on increasing productivity (PR), reducing variation and errors (VE) and reducing processing time (PT); as shown in Figure 4. Numbers of studies are slowly increasing from 2000 and peaked up to top in year range from 2005–2008. After that; there is a downfall which continues till 2017. Figure 4 shows the Bar chart showing the variations in number of studies; based on various parameters.

It is investigated that the point of convergence for most of the studies (42%) is on reducing processing time; whereas studies focusing on reducing variations and increasing productivity are 29% each; as shown in Figure 5. It emphasises the importance of time parameter in the healthcare sector. From the Figure 5, it can be interpreted that other factors like 'reducing variation' and 'increasing productivity' also play important role in healthcare sector but reducing processing time is the demand from patients' side that never goes out of phase as shown in Figure 4. Time parameter has got special attention in most of the studies in healthcare sector because delay of one or two minutes can make a difference in terms of life or death.

Figure 4 Bar chart for number of studies (see online version for colours)

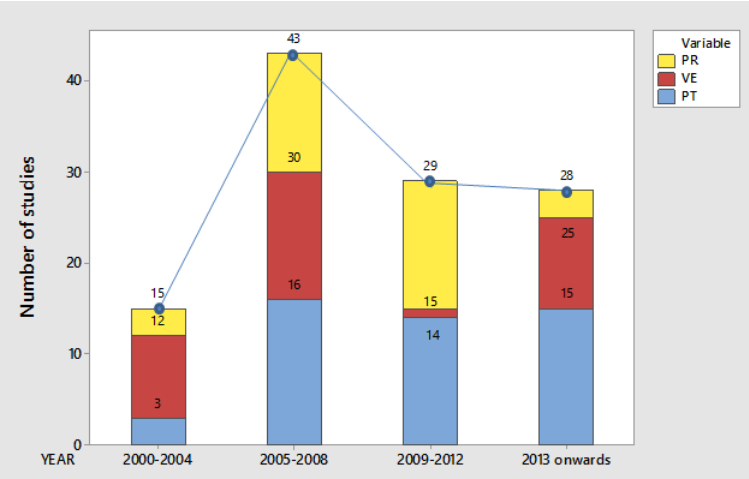
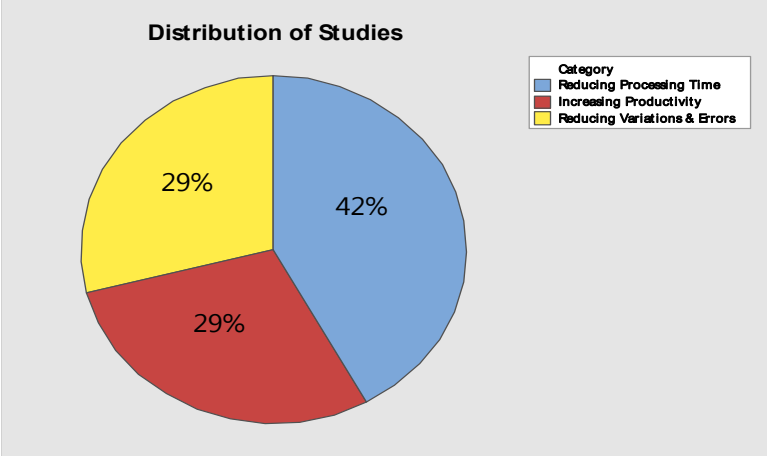


Figure 5 Distribution of studies in different areas (see online version for colours)



6.2 Analysis of studies using Pareto chart

Pareto chart was introduced by Vilfredo Pareto. He observed that 80% of the wealth in the Italy was held by 20% of the people. Similarly in case of manufacturing industry, the 80% of the problem are caused by 20% of the causes. So the ultimate aim of Pareto chart is to highlight the vital few from trivial many.

The Pareto chart analysis is performed for number of studies in different countries as shown in Figure 6. It is clear from the Figure 6 that most of the studies were performed in US followed by Netherlands and India.

The Pareto chart analysis has also been performed for number of studies in different departments; as shown in Figure 7. It can be observed that most of the studies were carried out in ED which was followed by surgery and radiology. Figure 7 shows the number of studies performed in various departments from 104 research papers and not included 11 papers; as these papers implemented Lean and Six Sigma in more than one department but shown in Table A2 (Appendix).

Figure 6 Pareto chart for number of studies in different countries (see online version for colours)

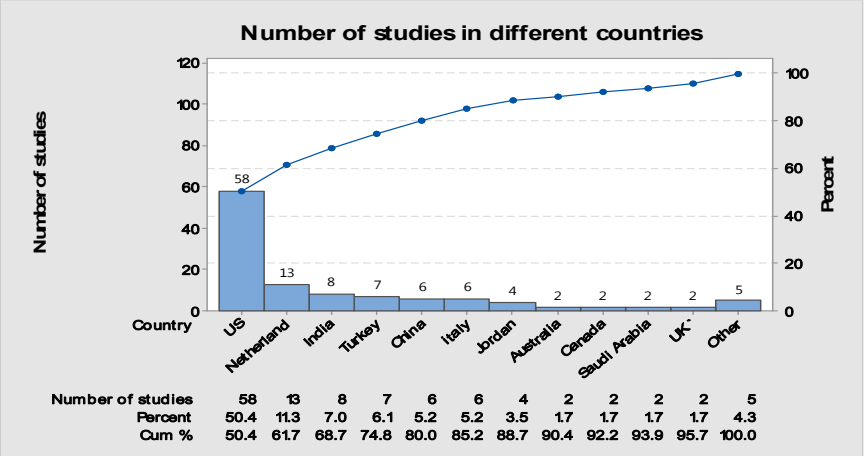
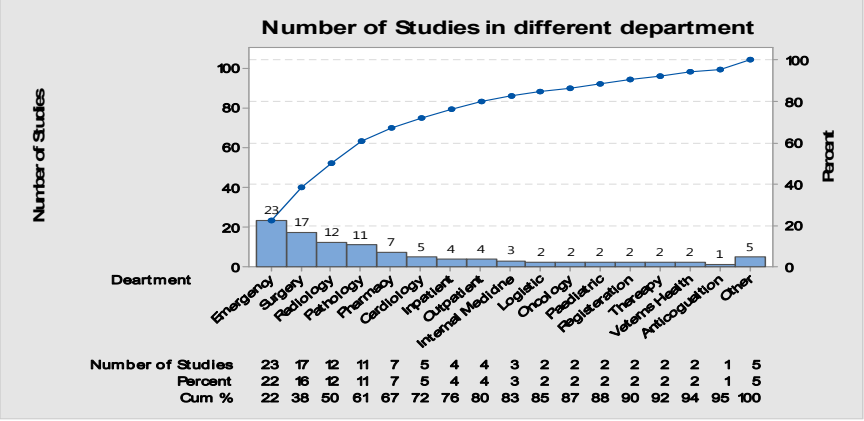


Figure 7 Pareto chart for number of studies in various departments (see online version for colours)



6.3 Analysis of studies using matrix plots

Matrix plot is a graph that can be used to find the relationship among different pairs of variable at the same time. It can also be defined as set of individual scatter plots. These are two types: matrix of plots and each Y verses each X.

Figure 8 helps us to know the distribution of number of studies in different departments across the time line from 2000 to 2017. The different rows in the Figure 8 show various departments. The matrix plot is drawn for those departments which accounts for maximum number of studies (can be seen from Figure 7).

Figure 9 shows the distribution of number of studies in different countries across the time line from 2000 to 2017. The plot includes the countries which accounts for maximum number of studies (can be seen from Figure 6).

Figure 8 Year wise matrix plot for number of studies in different departments (see online version for colours)

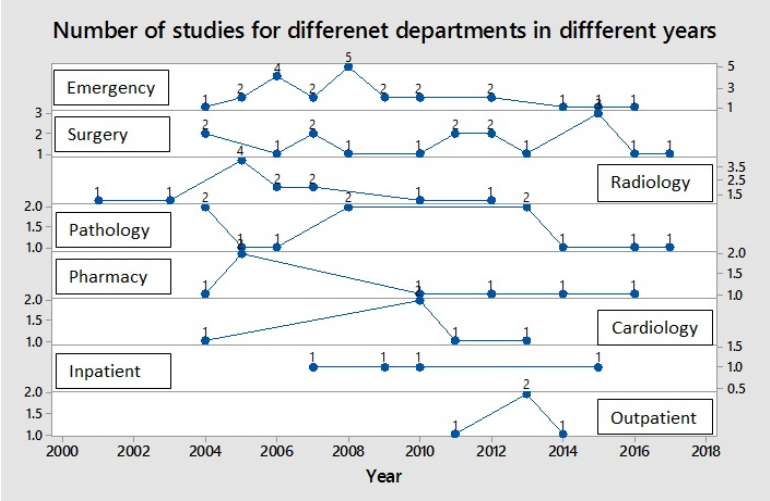
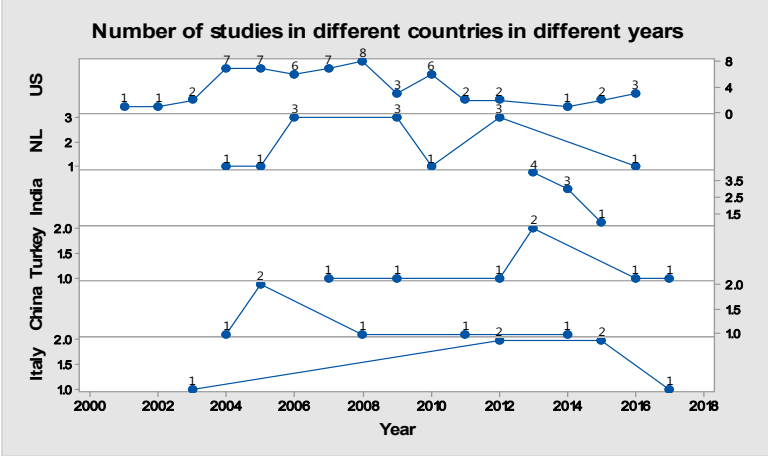


Figure 9 Year wise matrix plot for number of studies in various countries (see online version for colours)



Note: NL = Netherlands, US = United States.

7 Discussions

This section presents the discussion on the studies done in various countries and departments from 2000 to 2017. It is evident from the Figure 4 that number of studies focus on Lean Six Sigma applications in healthcare began since the year 2000 and continue to rise till 2008. After 2008, there is a little downfall in number of studies; but still there is great need to implement Lean Six Sigma in healthcare sector to reduce the errors in medication and operations to save the lives of patients. One thing can be noted that number of studies focused on reducing processing time never goes out of phase as there is no major downfall in these studies as shown in Figure 4. It shows the importance of time parameter in healthcare sector.

The trend in Figure 5 also demonstrates the effect of time parameter in healthcare sector; as most of the studies (42%) are focused on reducing processing time. The time is utmost important in hospitals because reduction of fraction of minute in processing time can save the lives of patients. This is the reason that most of studies are focused on reducing processing time like waiting time, TAT, cycle time and LOS in the hospitals.

It is also observed from the Figure 6 that 80% of studies have been carried out in US, Netherlands, India, China and Turkey. However, more than 50% of the studies were undertaken in US. This shows that there is a huge gap of deploying Lean Six Sigma in other countries. So there is great opportunity for other countries like India, Turkey, etc., to implement the Lean Six Sigma to its full potential. Similarly, it is concluded from the Figure 7 that more than 80% of the studies were performed in emergency, surgery, radiology, pathology, pharmacy, cardiology, inpatient and outpatient departments. However, 22% of the studies were performed in ED only. That shows the great necessity of Lean Six Sigma in ED to reduce cycle time, TAT, overcrowding, etc. But there is a great occasion to apply Lean and Six Sigma to other departments like paediatric, internal medicine, logistic, registration, etc.

It is clear from the Figure 8 that there is uniform distribution of applying Lean and Six Sigma in ED and SD throughout the time line. The uniform distribution means that the studies in these departments had been performed in regular interval in various years. Literature survey shows that ED is always associated with longer waiting time and overcrowded room and SD is overburdened with errors and inefficiencies. These are the possible reasons for applying Lean and Six Sigma at regular interval in these departments. In case of radiology and pathology, there is also a better distribution of studies throughout the years but not as uniform as for ED and SD. One of the reasons is that these departments involve less human interactions. The patient involvement is limited to sample collection, etc. That's why; there is limited scope for improvement. The Lean and Six Sigma are slowly expanding to pharmacy, cardiology inpatient and outpatient departments; as shown in Figure 8. So; there is a lot of scope of improvement in these departments in future. In Figure 9, it is demonstrated that there is continuous use of Lean and Six Sigma in the US throughout the years. That shows the strength and success of the US healthcare sector. The uneven distribution of these studies was found in some countries like India and China and needs to implement Lean and Six Sigma in the healthcare sector of these countries.

The Table A1 of the Appendix shows the departments and countries accounts for maximum number of studies (can be seen from Figure 6 and 7). The one cell represents number of studies in particular department and in particular country. It is shown that

more than 60% (70 out of 115) of the studies are simultaneously taken place in departments and countries selected from Pareto charts. That also shows a great gap of deploying Lean Six Sigma in other countries and departments. The categorisation of different studies according to department; country and year are given in Table A2 (Appendix).

8 Conclusions

Medical errors, variability and longer waiting lower down the possibility of safe and effective care of patients. This paper highlights the need of quality initiatives in healthcare industry as the medical errors are continuously increasing in this field. Although; there is a significant advancement in the technology from last few decades, but still many incidences of medical errors are being reported.

The literature survey shows that most of the studies are focused on reducing the processing time. It shows the importance of time parameter in healthcare sector. It is indicated by Pareto analysis that Lean Six Sigma implementation in healthcare organisations is limited across the globe. In addition, there are many departments like therapy, anticoagulation, etc. in healthcare sector where Lean and Six Sigma have not been applied yet. It is found that there is uniform distribution of applications of Lean and Six Sigma in ED and SD only, whereas in case of countries, only US shows continuous use of Lean and Six Sigma. There is a great opportunity to expand the applications of Lean Six Sigma in different departments in various countries. The healthcare personnel must seek training and guidance for implementing these quality initiatives with the support of top management.

The Six Sigma and Lean have showed their excellence in manufacturing industry and there are astounding results in terms of saving and revenue generation. But there is no generalisation of results for the healthcare industry. That's why; every healthcare organisation resists in implementing these quality initiatives. So there is great scope of quality improvement in healthcare and it will continue to grow in the future.

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Appendices

Table A1 Number of studies in departments and countries selected from Pareto chart

Department/country	*USA*	*Netherlands*	*India*	*Turkey*	*China*	*Italy*	*Total*
Emergency	Sanders and Karr (2015), Anguelov et al. (2008), Drenckpohl et al. (2007), Dickson et al. (2009), Eldridge et al. (2006), Frankel et al. (2005), Gelrud et al. (2008), Jimmerson et al. (2005), Parks et al. (2008), Shannon et al. (2006), Simmons-Trau et al. (2004), Berlanga and Husby (2016)	Heuvel et al. (2006a), Niemeijer et al. (2010), Niemeijer et al. (2012b)		Taner and Sezen (2009)	Chan et al. (2014), Pan et al. (2008)	Celeno et al. (2012)	19
Surgery	Southard et al. (2012), Kumar and Steinebach (2008), Adams et al. (2004), Fairbanks (2007), Parker et al. (2007), Pexton and Young (2004), Cima et al. (2011)	Niemeijer et al. (2012a)	Ramaswamy et al. (2015)	Taner (2013)		Bertolaccini et al. (2015), Improta et al. (2015), Montella et al. (2017)	13
Radiology	Bahensky et al. (2005), Jean and Sridhar (2001), Carrigan and Kujawa (2006), Gorman et al. (2007), Kim et al. (2007), Lloyd and Holsenback (2006), Yamamoto et al. (2010)			Taner et al. (2012)	Chan et al. (2005), Chen et al. (2005)	Cavagna et al. (2003)	11
Pathology	Sunyog (2004), Neri et al. (2008), Condel et al. (2004), Jackson and Woeste (2008), Raab et al. (2006b), Riebling and Tria (2005)	Basta et al. (2016)	Gijo et al. (2013), Sarkar et al. (2014)	Kutsal et al. (2017)			10
Pharmacy	Castle et al. (2005), Esimai (2005)				Chan (2004)	Chiarini (2012)	4
Cardiology	Raghavan et al. (2010), Elberfeld et al. (2004), Kumar (2010)			Taner et al. (2013)	Yeh et al. (2011)		5
Inpatient	Allen et al. (2010), Dupree et al. (2009), El-Eid et al. (2015), Furman and Caplan (2007)						4
Outpatient	LaGanga (2011)		Dinesh et al. (2013), Bhat and Jnanesh (2014), Gijo and Antony (2013)				4
Total	42	5	6	5	6	6	70

Table A2 Country and department wise distribution of studies

Sr. no.	*Reference and year*	*Area of research*	*Country*	*Department*
1	Taner and Sezen (2009)	Utilised the Six Sigma to reduce the turnover intentions of doctor in emergency services.	Turkey	Emergency
2	Sanders and Karr (2015)	Reduced the turnaround time of emergency department specimen with the utilisation of Lean Six Sigma approach.	USA	Emergency
3	Chan et al. (2014)	Improved the patient flow in an emergency department with the application of Lean techniques.	China	Emergency
4	Celano et al. (2012)	Provided a new roadmap by linking Lean Six Sigma with discrete event simulation and this roadmap was applied in different departments like audiology and cardiology.	Italy	Emergency
5	Mandahawi et al. (2010)	Reduced an emergency department waiting time with the help of design for Six Sigma and discrete event simulation software.	Jordan	Emergency
6	Anguelov et al. (2008)	Improved the patient flow in the emergency department over two years using Lean thinking.	USA	Emergency
7	Heuvel et al. (2006a)	Applied the Lean Six Sigma in Canisius Wilhelmina Hospital to reduce longer waiting time in emergency room.	Netherlands	Emergency
8	Niemeijer et al. (2010)	Took advantage of Lean Six Sigma techniques to improve the discharging procedure in trauma Nursing department.	Netherlands	Emergency
9	Drenckpohl et al. (2007)	Utilised Six Sigma methodology to reduce administration errors in breast milk.	USA	Emergency
10	Dickson et al. (2009)	Applied the Lean techniques in the emergency department of hospital to reduce LOS.	USA	Emergency
11	Eldridge et al. (2006)	Used the Six Sigma process in four intensive care unit (ICU) to implement the centre for disease control and prevention (CDC) guidelines for hand hygiene.	USA	Emergency
12	Frankel et al. (2005)	Lowered down the incidence of catheter related bloodstream infections (CR-BSI) in SICU.	USA	Emergency
13	Gelrud et al. (2008)	Addressed the problem of longer TAT in emergency department.	USA	Emergency
14	Ben-Tovim et al. (2007)	Used the Lean thinking to redesign the care at Flinders Medical Centre.	Australia	Emergency
15	Jimmerson et al. (2005)	Lowered down the waste as well as errors using Toyota production system.	USA	Emergency
16	King et al. (2006)	Redesigned the emergency department (ED) with the help of Lean thinking.	Australia	Emergency
17	Pan et al. (2008)	Applied the Six Sigma and health quality improvement circle approach to reduce the unplanned endotracheal extubation (UEE).	China	Emergency
18	Niemeijer et al. (2012b)	Used Lean Six Sigma approach for declining in overuse of diagnostic test for trauma patients.	Netherlands	Emergency
19	Parks et al. (2008)	Used Lean Six Sigma to reduce the delays in trauma care.	USA	Emergency
20	Shannon et al. (2006)	Utilised the Toyota production system to eliminate the central line infections in America because every year 200,000 Americans died due to central line-associated bloodstream infections (CLABs) with 15–20% mortality.	USA	Emergency

Table A2 Country and department wise distribution of studies (continued)

Sr. no.	*Reference and year*	*Area of research*	*Country*	*Department*
21	Simmons-Trau et al. (2004)	Used Six Sigma to shorten the ventilator associated pneumonia (VAP).	USA	Emergency
22	Khurma et al. (2008)	Improved the patients experience in their hospital stay at ED using Lean approach. Simulation based models were developed to compare the current and future state.	Canada	Emergency
23	Berlanga and Husby (2016)	Made use of Six Sigma and Lean principles to shorten the emergency waiting time in Texas Medical Centre.	USA	Emergency
24	Sedlack (2010)	Utilised the Six Sigma as well as statistical process control techniques in order to reduce the waiting time of surgeon between the cases and length of stay after colon surgery.	UK	Surgery
25	Taner (2013)	Applied the Six Sigma methodology to lower down the intra-operative and postoperative complications in Cataract Surgery of the Turkish Public Hospital.	Turkey	Surgery
26	Southard et al. (2012)	Utilised the radio frequency identification (RFID) in healthcare along with Six Sigma DMAIC and discrete event simulation in outpatient surgical process.	USA	Surgery
27	Peltokorpi and Kujala (2006)	Correlated the work in progress concept with patient in process and along with DMAIC approach applied it to hip replacement case study.	Finland	Surgery
28	Kumar and Steinebach (2008)	Reduce the medical errors in surgery process of US hospital. Errors involved pain, complications, etc.	USA	Surgery
29	Mandahawi et al. (2011)	Applied the Lean Six Sigma tools to reduce the length of stay for ophthalmology day case surgery.	Jordan	Surgery
30	Adams et al. (2004)	Practiced Six Sigma initiatives to reduce the TAT between the surgery cases.	USA	Surgery
31	Ramaswamy et al. (2015)	Lowered the average residual spherical errors for the improvement in postoperative visual outcome following cataract surgeries using Lean Six Sigma approach.	India	Surgery
32	Fairbanks (2007)	Improved the OR throughput with the use of Lean and Six Sigma.	USA	Surgery
33	Niemeijer et al. (2012a)	Reduced the LOS for hip fracture.	Netherlands	Surgery
34	Parker et al. (2007)	Improved the cycle timing of antibiotic prophylaxis with the target of less than 60 minutes before incision.	USA	Surgery
35	Pexton and Young (2004)	Reduced the surgical site infections using Six Sigma Six Sigma philosophy.	USA	Surgery
36	Cima et al. (2011)	Improved the efficiency of operating room using Lean and Six Sigma in Academic Medical Centre.	USA	Surgery
37	Bertolaccini et al. (2015)	Utilised the Lean Six Sigma methodologies in order to reduce the complications during and after lobectomies.	Italy	Surgery
38	Gheysari et al. (2016)	Reduced the cancellation of surgery using Lean Six Sigma approach.	Iran	Surgery
39	Improta et al. (2015)	Utilised the Lean Six Sigma approach for the reduction of LOS in prosthetic hip replacement surgery.	Italy	Surgery
40	Montella et al. (2017)	Lowered down the number of patients affected by sentinel bacterial infections using Lean Six Sigma methodology.	Italy	Surgery

Table A2 Country and department wise distribution of studies (continued)

Sr. no.	*Reference and year*	*Area of research*	*Country*	*Department*
41	Taner et al. (2012)	Improved the work flow in diagnostic imaging process using Six Sigma.	Turkey	Radiology
42	Bahensky et al. (2005)	Reduced the cycle time for CT scanning by Lean Six Sigma approaches.	USA	Radiology
43	Jean and Sridhar (2001)	Shortened the process variability in the radiology department with Six Sigma approach.	USA	Radiology
44	Carrigan and Kujawa (2006)	Discussed the Six Sigma applications in improving the emergency medical services billing accuracy.	USA	Radiology
45	Chan et al. (2005)	Utilised Six Sigma methodology to improve the magnetic resonance imaging (MRI) capacity	China	Radiology
46	Chen et al. (2005)	Made use of Six Sigma to turn down the defect ratio of films in the radiology department.	China	Radiology
47	Gorman et al. (2007)	Used the Six Sigma DMAIC model to improve the documentation and communication radiology preliminary and final reports.	USA	Radiology
48	Kang et al. (2005)	Used the Six Sigma approach to improve the quality of picture archiving and communication system (PACS) and reduce the resource required for its management.	South Korea	Radiology
49	Kim et al. (2007)	Improved the quality of patient care with bone and brain metastases using Lean thinking.	USA	Radiology
50	Cavagna et al. (2003)	Optimised the process of radiology reports with a view to provide the 100% service delivery within 72 hours to outpatients and 36 hours to inpatients.	Italy	Radiology
51	Lloyd and Holsenback (2006)	Applied Six Sigma to the Radiology Department of Commonwealth Health Corporation to reduce the MRI ordering process error.	USA	Radiology
52	Yamamoto et al. (2010)	Utilised the Six Sigma to improve the productivity of inpatient insulin administration affected by the meal delivery and radiology test.	USA	Radiology
53	Gijo et al. (2013)	Utilised the Lean and Six Sigma tools to reduce waiting time of patient in pathology department of a multispecialty hospital.	India	Pathology
54	Elbireer et al. (2013)	Reduced the errors in laboratory data entry using Six Sigma approaches.	Uganda	Pathology
55	Sunyog (2004)	Applied Lean and Six Sigma in hospital clinical laboratory to systematically eliminate the waste and minimise the variation.	USA	Pathology
56	Neri et al. (2008)	Utilised the Six Sigma approach to control the utilisation of blood product.	USA	Pathology
57	Condel et al. (2004)	Took advantage of Lean production methods in order to make pathology department error free.	USA	Pathology
58	Jackson and Woeste (2008)	Made use of Lean Six Sigma techniques to reduce the waiting time of patients in phlebotomy department.	USA	Pathology
59	Sarkar et al. (2014)	Specially outlined the importance of 'Control phase' of DMAIC procedure of Six Sigma in medical test completion.	India	Pathology
60	Raab et al. (2006b)	Focused on reducing the medical errors by improving Papanicolaou test quality with the help of Toyota production system.	USA	Pathology

Table A2 Country and department wise distribution of studies (continued)

Sr. no.	*Reference and year*	*Area of research*	*Country*	*Department*
61	Riebling and Tria (2005)	Applied the Six Sigma DMAIC approach to reduce the errors in automated lab.	USA	Pathology
62	Basta et al. (2016)	Utilised the combined Lean and Six Sigma approach in order to decrease the dispatch time of medical reports.	Netherlands	Pathology
63	Kutsal et al. (2017)	Improved histopathology laboratory productivity using Six Sigma and A3 problem solving.	Turkey	Pathology
64	Al-Araidah et al. (2010)	Cut down the lead time at the inpatient pharmacy of a hospital.	Jordon	Pharmacy
65	Arafeh et al. (2014)	Applied Six Sigma to decrease the patient waiting time in outpatient pharmacy located in cancer treatment hospital.	Jordon	Pharmacy
66	Castel et al. (2005)	Utilised the Six Sigma methodology to shorten the medication errors of home delivery service in pharmacy.	USA	Pharmacy
67	Chan (2004)	Took the project to compress the dispensing errors in pharmacy of outpatient clinic because the pharmacy dispensing errors ranked second in list of errors in Taiwan.	China	Pharmacy
68	Chiarini (2012)	Applied the Lean and Six Sigma approach to increase the safety of staff and nurses who manage the cancer drugs.	Italy	Pharmacy
69	Kuwaiti (2016)	Applied the Six Sigma DMAIC process to reduce the medical errors in the outpatient pharmacy.	Saudi Arabia	Pharmacy
70	Esimai (2005)	Brought into play Six Sigma to lower down medication errors.	USA	Pharmacy
71	Yeh et al. (2011)	Applied the Lean Six Sigma tools to minimise the cycle time of door to balloon process of Acute myocardial infraction.	China	Cardiology
72	Taner et al. (2013)	Made use of Six Sigma to lower down the number of complications occurred during coronary stent insertion process.	Turkey	Cardiology
73	Raghavan et al. (2010)	Shorten the patient TAT in Cardiac Catheterisation Lab of US Community Hospital with the applications of Lean Six Sigma technique.	USA	Cardiology
74	Elberfeld et al. (2004)	Improved the quality of patient care in acute myocardial infraction (AMI) and congestive heart failure (CHF) using Six Sigma philosophy.	USA	Cardiology
75	Kumar and Thomas (2010)	Proposed a process flow model for diagnosis and treatment of chest pain using Six Sigma DMAIC.	USA	Cardiology
76	Allen et al. (2010)	Improved the hospital discharge process with five phases of Six Sigma DMAIC approach.	USA	Inpatient
77	Dupree et al. (2009)	Utilised the Six Sigma DMAIC approach for the pain management of two inpatients unit in the Urban Academic Medical Centre.	USA	Inpatient
78	El-Eid et al. (2015)	Lowered down the discharge time consisted of discharge orders to patient actually leave the room using Six Sigma DMAIC philosophy.	USA	Inpatient
79	Furman and Caplan (2007)	Reduced the error in Virginia Mason Medical Centre by using Lean approach.	USA	Inpatient
80	Dinesh et al. (2013)	Used the Six Sigma approach in order to lower down the waiting time in the outpatient cardiology office in India.	India	Outpatient

Table A2 Country and department wise distribution of studies (continued)

Sr. no.	*Reference and year*	*Area of research*	*Country*	*Department*
81	Bhat and Jnanesh (2014)	Adopted the Lean Six Sigma tools in rural hospital to diminish the cycle time of outpatient department services.	India	Outpatient
82	Gijo and Antony (2013)	Made use of Lean Six Sigma methodology in order to lower down the patient waiting time in Outpatient department.	India	Outpatient
83	LaGanga (2011)	Used the Lean thinking to increase the capacity of outpatient clinic.	USA	Outpatient
84	Heuvel et al. (2005)	Applied the Lean Six Sigma approach to reduce the errors in the invoice from temp agencies, reduce the number of errors in invoices issued to patient and insurance companies and in another project reduces the LOS in children department.	Netherlands	All
85	Heuvel et al. (2006b)	Optimised the use of operating rooms (ORs) with just simple steps to increase the productivity, reduced the number of patients receiving Intravenous antibiotics (IV) by switch to oral administration and reduced the delivery room LOS.	Netherlands	All
86	Heuvel et al. (2004)	Employed Six Sigma approaches in order to reduce the preparation time for intravenous medication and to reduce the LOS of gynaecology patients.	Netherlands	All
87	Koning et al. (2006)	Lowered down the number of mistakes in the invoices and optimised the operating theatre utilisation through Six Sigma methodology.	Netherlands	All
88	Christianson et al. (2005)	Decrease the LOS for admissions to orthopaedics department, reduce cycle time in emergency department, reduced patient preparation cycle time and increased the rate of patient encounter that are free from medication related harm.	USA	All
89	Taner et al. (2007)	Reduced the unnecessary laboratory test in paediatric and obstetrics gynaecology wards, increase the MRI image quality, reduce the catheter infections after surgery, reducing LOS in hospital affected by discharge planning process and reduced the waiting time of patients before surgery.	Turkey	All
90	Niemeijer et al. (2012c)	Lowered down the unnecessary diagnostic test for trauma patient with Six Sigma, reduced the cost of implant and equipment, surgeon used for their surgery and in other project increased the productivity by reducing the material usage in trauma ward.	Netherlands	All
91	Lighter (2014)	Lowered down the medication and fluid administration errors in the weight determination of paediatric burn patients and decrease the waiting time for MRI.	USA	All
92	Sagy (2009)	Took advantage of Six Sigma philosophy to provide downfall in medication order defects.	USA	All
93	Johnstone et al. (2003)	Used the Six Sigma in Naval Medical Centre to investigate the errors for various processes such as pharmacy, radiology, blood bank etc. within ancillary services.	USA	All
94	Sehwail and DeYong (2003)	Improved the patient and physician satisfaction using Six Sigma in Mount Carmel health system.	USA	All
95	Fischman (2010)	Used the Lean Six Sigma methodologies in internal medicine residency clinic to improve patient-physician familiarity, work flow process and continuity of care.	USA	Internal medicine
96	Bisgaard and Does (2009)	Reduced the LOS at hospital using DMAIC model of Six Sigma.	Netherlands	Internal medicine

Table A2 Country and department wise distribution of studies (continued)

Sr. no.	*Reference and year*	*Area of research*	*Country*	*Department*
97	Raab et al. (2006a)	Stepped down thyroid gland fine-needle aspiration error using Lean technique.	USA	Internal medicine
98	Bhat et al. (2014)	Utilised the Lean Six Sigma to reduce the registration process cycle time.	India	Registration
99	Yu and Yang (2008)	Used the Lean and Six Sigma approaches to reduce the registration waiting time of the patients.	USA	Registration
100	Silva et al. (2012)	Used the Lean Six Sigma approach to improve the inventory quality control in clinical engineering.	Brazil	Logistic
101	Jin et al. (2008)	Designed and operated a healthcare logistic centre using Six Sigma and Lean approach.	USA	Logistic
102	Bush et al. (2007)	Significantly lowered down the waiting time in women medical centre clinic using Six Sigma DMAIC philosophy.	USA	Paediatric
103	Wijma et al. (2009)	Improved the efficiency of nursing department using Lean Six Sigma approach.	Netherlands	Paediatric
104	Lent et al. (2009)	Used the Lean approach to improve the efficiency of chemotherapy day unit.	Netherlands	Therapy
105	Guinane and Davis (2004)	Applied Six Sigma to reduce the groin injuries in the hospital.	USA	Therapy
106	Nayar et al. (2016)	Made use of Lean Six Sigma approach to develop recommendations and implement effective process in medication management of dual care veteran patients.	USA	Veterans health
107	Pocha (2010)	Reduced the number of portable chest X-rays in emergency room.	USA	Veterans health
108	Celik et al. (2016)	Used the Six Sigma approach in order to lower down the inoperability among lung cancer patients.	Turkey	Oncology
109	Baril et al. (2016)	Made use of Lean approach along with Kaizen and discrete event simulation in order to reduce the patient delays in receiving their treatment.	Canada	Oncology
110	Bhat and Jnanesh (2013)	Enhanced the performances of health record preparation process in health information department.	India	Information
111	Smith et al. (2012)	Applied Lean thinking along with kaizen in public health practice to reduce operational cost and working conditions.	USA	Home healthcare
112	Jushuf and Griffiths (2007)	Lowered down the follow up and increased the capacity of genitourinary (GU) medicine services in UK.	UK	Genitourinary medicine
113	Kooy et al. (2002)	Utilised Six Sigma to improve the safety and efficiency of acute anticoagulation with heparin.	USA	Anticoagulation
114	Faiomy and Shabana (2012)	Shortened the waiting time entering to vaccination room.	Saudi Arabia	Vaccination
115	Barrios and Jiménez (2016)	Made use of Six Sigma methodology to shorten the lead time of appointments in Obstetrics Department of Maternal Child Hospital in Colombia.	USA	Obstetrics