Reducing pharmacy medication errors using Lean Six Sigma: A Thai hospital case study

Reducing Pharmacy Medication Errors using Lean Six Sigma: A Thai Hospital Case Study

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Abstract

Hospital medication errors are costly and contribute to patient mortality, morbidity, and decreased health care quality. Errors result from poor systems design more commonly than from healthcare staff performance. As such, a focus should be directed to process design. This action research study examines the application of Lean Six Sigma to reduce inpatient pharmacy dispensing errors in a Thai public hospital. Through the successful application of multiple Lean Six Sigma tools, the implementation of Lean Six Sigma reduced monthly dispensing errors from 29 incidents to 6 incidents over 14,000 total inpatient days between March 2018 and November 2019, and improved patient safety. Lean Six Sigma tools used in this study were cause-and-effect diagrams, spaghetti diagrams, five-why analysis, project charters, brainstorming, control charts, and hypothesis testing. This case study can improve hospital manager and medical director awareness of Lean Six Sigma and its benefits relative to the prevention and reduction of medication errors.

Keywords: Lean Six Sigma; Quality Improvement; Patient Safety; Medication Errors; Pharmacy

Introduction

Although Lean Six Sigma (LSS) has found abundant application in healthcare over the last few decades, it has not heretofore been used to reduce errors in a specific area with potential life-and-death consequences: inpatient medication dispensing errors. The present study aims to close that gap by demonstrating the value of LSS application to reduction of in inpatient pharmacy medication dispensing errors in a Thai hospital. As a by-product, rather than as an intentional result of this demonstration, application of specific and commonly used tools and methods were found to contribute in LSS define–measure–analyze–improve–control (DMAIC) phases where such methods have not previously been used in medication dispensing processes, whether in inpatient or other medication dispensing contexts.

Recent studies identify medication errors as a global issue. Patients should receive correct dosages and concentrations of prescribed medication on time throughout the treatment regimen. Medication process errors result whenever an error is made in medication prescription, transcription, dispensing, administration, and/or monitoring (Lisby et al., 2005; Baril et al., 2014). Prescription errors in the UK reportedly affect 12% of primary care patients and 38% of patients aged 75 and older (World Health Organization, 2016). Prescription administration error rates in Australia range from 15% to 20% (Runciman et al., 2003), while 58% of prescriptions in Mexico contain errors, predominantly due to dosage regimen and inappropriate drug selection (World Health Organization, 2017).

In Thailand, despite several attempts to protect patients in hospitals, medication errors remain a serious problem for patient safety mainly due to inadequate hospital quality management systems (Limpanyalert, 2018). Correcting the consequence of medical errors is costly. For example, in 2016, the National Health Security Office paid an average of USD 7,200 per case to 885 patients and/or their families who had suffered the undesirable consequences of medical error (National Health Security Office, 2016). The seriousness of this problem in Thailand is sufficient to motivate an in-hospital case study as a means of "doing good in real time", while also learning what works, what doesn't, and what portions of solutions are applicable in other hospital pharmacies or in other contexts.

Medication dispensing involves preparing and giving medicine to a patient, based on a prescripton or medication order (Weant, Bailey, and Baker, 2014). Dispensing is complex and errors can occur at any stage, from receiving medication orders/prescriptions to supplying medication to a specific patient (James et al., 2009). If not detected in the pharmacy department, errors may result in injury, death and/or economic loss.

Although pharmacists identify and correct the majority of errors before dispensation, approximately 134,000 dispensing errors occur annually in English or Welsh pharmacies (James et al., 2009). A global review of dispensing errors indicated rates between 11.5% and 33.5% in Brazil, compared to 0.016% to 3.6% in the UK, USA and France (Aldhwaihi et al., 2016). Lacking national data and medication error reporting systems, dispensing error rates have not been reported in many developing nations, including Thailand. Interestingly, the dispensing process within hospital settings (e.g. inpatient service) is deemed to be more complex than that of non-hospital settings (e.g. community pharmacy). When compared with a community pharmacy, hospital pharmacists dispense through a more complex regimen which can lead to a high occurrence of errors (Aldhwaihi et al., 2016). Continuous improvement methodologies such as Lean and Six Sigma can be very useful in improving the dispensing process in a hospital setting.

Lean and Six Sigma which integrated in the 1980s as Lean Six Sigma (LSS) (George, 2003), can be used to drive continuous medication dispensing improvement (Trakulsunti and Antony, 2018). LSS eliminates waste and reduces variation to improve process performance. LSS implementation in healthcare, particularly in hospitals, has reduced costs and improved quality of care, patient safety, and staff and patient satisfaction (Edgeman, 2002; Cheng et al., 2015; Trzeciak et al., 2018; Ramori et al., 2019; Bhat et al., 2020). One USA LSS application reduced medication administration errors by more than 50 percent (van de Plas et al., 2017).

This case study is novel and important as no prior LSS studies have targeted dispensing error reduction in public hospital inpatient pharmacy services. Instead, medication error research has largely focused on reducing prescribing and administration errors (Kaosayapandhu, 2013). Although medication dispensing error rates are generally low, potentially lethal consequences motivate further research aimed at the identification and implementation of pharmacy distribution system interventions and improvements (Crane and Crane, 2006). This case study aims to examine the use and implemenation of LSS and associated tools and techniques to address the following research questions:

(1) Is LSS suitable for reducing hospital medication errors?

(2) What are the benefits, challenges, success factors, and lessons learned from implementing LSS to reduce medication errors?
(3) What LSS tools and techniques can be used to reduce medication errors?

Literature Review

A review of the current literature was conducted to evaluate current research practices. First a general review of the literature on LSS in healthcare is provided, followed by discussion of research more specific to the application of LSS in reducing medication errors.

LSS in Healthcare

To improve process performance and reduce variation, LSS studies process flow and identifies root causes of waste (Snee, 2010). Together, Lean and Six Sigma accelerate process speed (Lean) and improve consistency (Six Sigma), delivering better outcomes together than separately (George, 2002; Salah et al*.,* 2010).

Studies show that LSS can improve complex processes and quality of care, patient safety, and staff and patient satisfaction. Features differentiating LSS from previous quality improvement approaches include: 1) the integration of human factors (e.g. leadership and customer focus) and process improvement aspects (e.g. process capability and process management); 2) improved bottom line results; and 3) a structured DMAIC approach (Antony, 2011). While an LSS project begins with an understanding of customers' needs and the identification of factors that are critical to the patient (Burgess and Radnor, 2013), the successful implementation of LSS requires leadership commitment and engagement so that staff are appropriately supported, directed and encouraged (Trakulsunti and Antony, 2018). In process improvement strategies such as LSS, senior leaders are typically involved in the selection of strategic projects which are aligned with the voice of the customer. This is facilitated by the used of the Hoshin Kanri tool, a lean management tool (Edgeman, 2019). The participation of senior management was never emphasized in the majority of previous quality improvement initiatives, including TQM.

LSS is a widely adopted and well-documented process improvement manufacturing methodology in use across all highly reliable and safe industries (e.g. aviation, US Navy) (Dumitrescu and Dumitrache, 2011). The major benefits of successful LSS implementation within the manufacturing domain include; increased profits and financial savings, increased customer satisfaction, reduced operational cost and cycle time and improved key performance metrics (Snee, 2010). Laureani et al. (2013) contend that LSS can contribute as much to healthcare as it has to manufacturing. While the Commonwealth Health Corporation successfully implemented LSS in 1998, LSS has since been applied in other healthcare organisations, including, hospitals and healthcare functional areas (Thomerson, 2001).

As in other industries, LSS implementation in healthcare has encountered many barriers (Laureani et al., 2013), including large initial training investment (Taner et al., 2007) and obtaining baseline process performance data (Antony et al., 2007). Despite such barriers, successful LSS implementation in hospitals has delivered patient waiting time reduction in a registration process (Bhat, Gijo, and Jnanesh, 2014), reduced medical records department turnaround time (Bhat, Gijo, and Jnanesh, 2016), and reduced medication errors (Esimai, 2005; Benitez et al*.,* 2007; Antony et al., 2019). Four case studies using LSS to reduce medication errors noted many improvements including; enhanced patient safety, increased patient satisfaction, reduced costs, and greater team communication and improved team dynamics (Trakulsunti and Antony, 2018).

LSS in Reducing Medication Errors

Chan (2004) cites a Lean Six Sigma implementation strategy to deal with dispensing errors in a Taiwanese pharmacy department. In this implementation, the DMAIC (Define, Measure, Analyse, Improve and Control) methodology was applied. In the define phase, the 'voice of the customer' was defined to understand the patients' needs. During the measure phase, both historical and manually collected data were examined in order to establish a baseline for the performance of the process. During the analyse phase, process mapping tools were applied to the dispensing process, in order to identify issues in the process. In the Improve phase, brainstorming techniques were used to generate solutions; as an example, an automatic dispensing machine was used to reduce dispensing errors. Lastly, in the control phase, a control chart was employed to sustain improvements.

The successful implementation of LSS in this Taiwanese pharmacy department resulted in a 30% reduction of dispensing errors (Chan, 2004). In another study Esimai (2005) used LSS in a mid-sized US hospital to lower labour costs by $550,000 over a five-month span, while reducing order entry errors from 0.33% to 0.14%. Similarly, the application of LSS in a mid-sized US hospital reduced the number of missed doses and other hospital inpatient pharmacy errors, resulting in savings of $82,650 annually (Hintzen et al., 2009). The use of LSS in a US hospital setting resulted in hospital transcription and order entry errors falling by 90% over a four month period (Benitez et al., 2007). Conversely, the application of LSS in Norwegian public healthcare is currently in its infancy (Antony et al., 2019).

In summary, successful LSS implementation has improved staff performance, patient safety, overall satisfaction and hospital profitability, in addition to reducing medication errors (Ching, 2013).

Research Case Study

This study is based in the inpatient pharmacy service of a large public 508 bed-hospital under Thailand's Ministry of Public Health. The inpatient pharmacy uses a daily dose system to distribute medication via medication carts to 12 wards. It receives medication carts at 10:30 am and 2:00 pm, enabling ward staff to collect medication carts by 11:00 am and 3:00 pm, respectively. Five medication carts are received in the morning and seven in the afternoon. Five pharmacy technicians prepare 24 medication carts, 12 of which are delivered that day and the remaining 12 the succeeding day.

Research Methodology

The action research methodology was used in this study to improve the medication dispensing process. The project team, comprising the inpatient pharmacy head, two pharmacists, and three pharmacy technicians followed five action research stages: problem identification, reflection, planning action, taking action and evaluation. During the taking action phase, the project team followed the DMAIC methodology, applying specific LSS tools in each DMAIC phase. Table 1 summarizes the DMAIC methodology process. In addition, a questionnaire was used as a survey instrument to measure the patient's satisfaction with the quality of pharmacy services before and after the LSS implementation. The survey was carried out pre and post LSS implementation with a purposive sampling of 30 inpatients. The inpatients were chosen based on the following selection criteria: 1) they had stayed in the inpatient wards for more than 24 hours and were then discharged to their homes and 2) they were able to answer the questionnaire.

Define Phase

A project charter clarified team member roles and responsibilities and helped the team to focus on the project goals. This charter captured basic project details, including the problem statement, project scope, goal, and schedule (Figure 1). Process mapping (Figure 2) and a spaghetti diagram revealed inpatient pharmacy dispensing process improvement opportunities. As process mapping graphically represents process activities, it aids the identification of existing process steps and unnecessary dispensing process redundancy. The process map includes six main steps: 1) pharmacists receive and verify medication orders; 2) medication orders are entered in the E-hospital system; 3) medication order labels are printed; 4) pharmacy technicians collect and put medications into dedicated medication cart drawers for each patient; 5) a pharmacist who did not enter the order cross-checks medications; and 6) medication carts are delivered to the wards. During the define phase, two main problems were identified:

(1) Pharmacists can enter medication orders incorrectly into the E-hospital system,
(2) Pharmacy technicians can select medications incorrectly.

As dispensing errors occurred daily, particularly during busy periods, the identified process problems needed to be improved to reduce medicine dispensing process variation, mitigate patient harm potential, and reduce hospital costs and financial risk.

Figure 1 Project charter

<table>
<tr><th colspan="2">Project Charter</th></tr>
<tr><th>Customer(s)</th><th>Customer CTQ</th></tr>
<tr><td>Inpatients</td><td>Number of dispensing errors</td></tr>
<tr><th>Problem Statement</th><th>Potential Benefits</th></tr>
<tr><td>Dispensing errors occurred daily especially in the busy period in the inpatient pharmacy. The average number of dispensing errors that cannot be detected by the pharmacists between March 2017-March 2018 were 23 errors. The dispensing errors could lead to patient injury and death and contribute to an increase in hospital costs.</td><td>Reduce dispensing errors, improve patient safety and staff satisfaction</td></tr>
<tr><th>Goal Statement</th><th>Project scope</th></tr>
<tr><td>The goal is to reduce the number of dispensing errors in an inpatient pharmacy by 50%.</td><td>the pharmacies received the medication orders until medication cards are delivered to different wards</td></tr>
<tr><th>Schedule</th><th>Potential Team Members</th></tr>
<tr><td>Phase / Start / Finish
Define / Apr 2018 / May 2018
Measure / Jun 2018 / Jul 2018
Analyse / Jul 2018 / Aug 2018
Improve / Sep 2018 / Dec 2019
Control / Jan 2019 / Jan2020</td><td>Team leader: Researcher
Team members:
Head of Inpatient Pharmacy
Pharmacist 1
Pharmacist 2
Technician Pharmacy 1
Technician Pharmacy 2</td></tr>
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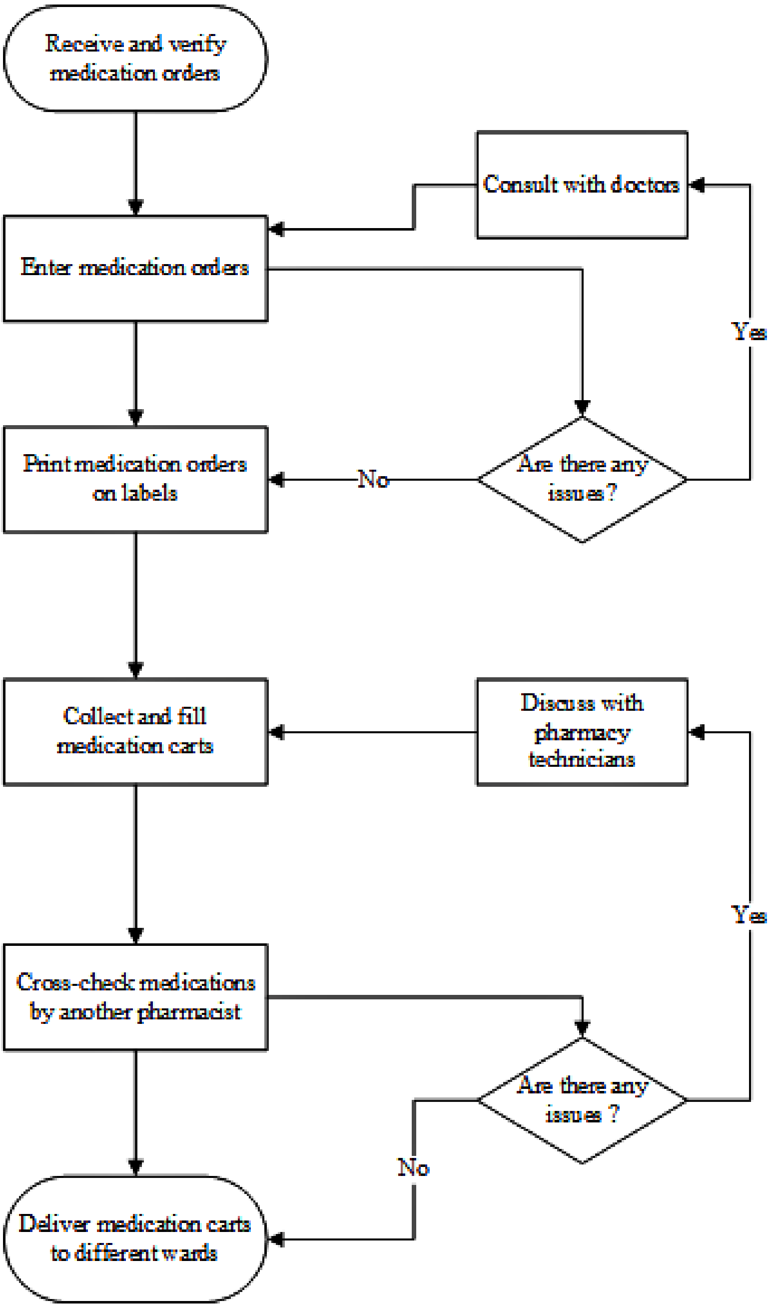

Figure 2. Medication dispensing process map

Measure Phase

The measure phase translates problems into measurable forms. Current process data was gathered to establish the medication dispensing process baseline performance (Gijo and Antony, 2014; Gijo et al., 2013). A data collection plan ensured collection of appropriate and reliable data (Table 2). The team used dispensing errors as the measured critical-to-quality (CTQ) characteristic, defining these as medication errors undetected by inpatient pharmacy pharmacists. The number of dispensing errors was used to assess dispensing process performance. Dispensing errors detected by the nurses had been reported in the hospital risk management system over a period of 25 months. Since sample sizes varied, error proportions were plotted on a P-chart. This chart showed an average dispensing error proportion of approximately 0.0018 (Figure 3). The dispensing process was out-of-control with one point falling beyond control limits and four points had a more than 1σ from the average error proportion, highlighting lack of strictly practiced standard operating procedures (SOPs).

Table 1 A data collection plan

Metric	Type of Measure	Type of data	Operational definition	Source of data	Collection method
(undetected) dispensing errors	Output	Discrete (counts of errors)	The errors that occurred at the end of dispensing process which were undetected by the pharmacists	Using existing data	Nurses report to Hospital Risk Management system

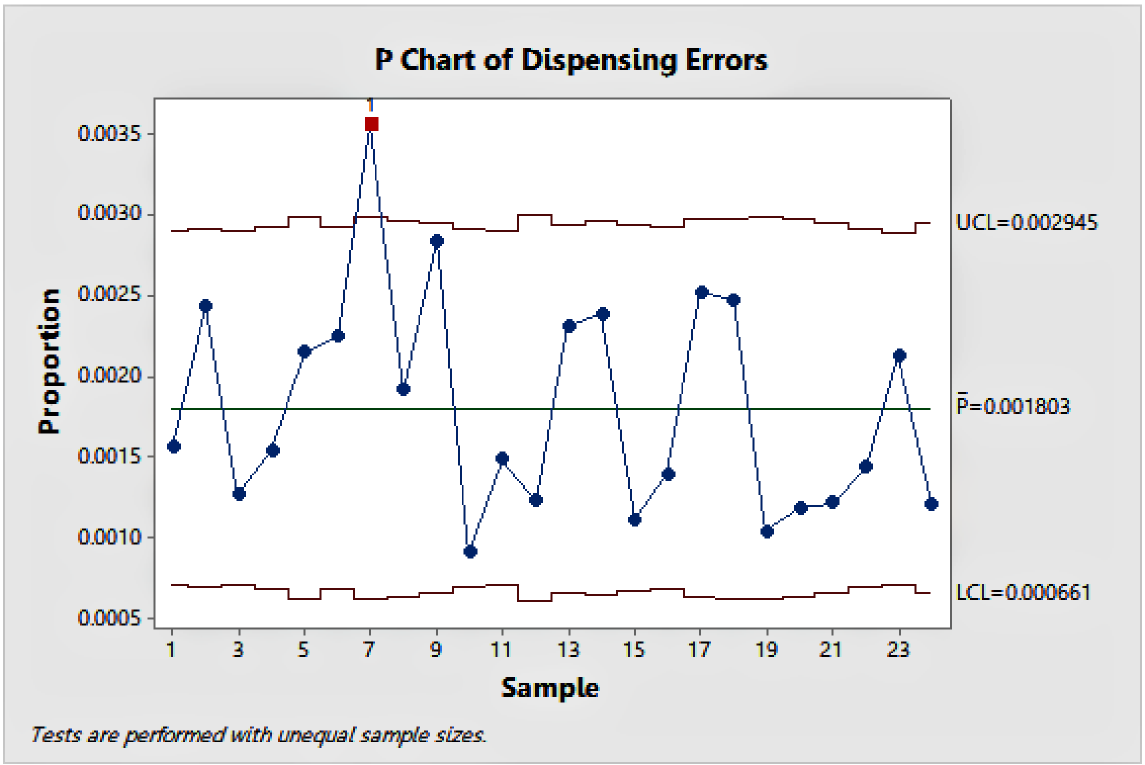

Figure 3. P-chart of proportion of medication dispensing errors per month.

Analyse Phase

Potential causes of incorrect medication order entry and incorrect medication selection were brainstormed, and visually portrayed using cause-and-effect diagrams (Figures 4 and 5). Multi-voting prioritized the three most prevalent causes: interruptions due to incoming medication orders from wards, misinterpretation of handwritten medication orders, and being rushed. Similarly, leading causes of incorrect medication selection were: interruptions from more medication orders, non-compliance with standard medication selection procedures, and being rushed. Five-Why analysis was used to drill into root causes of leading potential sources of each problem (Tables 3 and 4). The Pharmacy Head served as team facilitator and repeatedly asked pharmacists and pharmacy technicians why the problems had occurred until root causes were identified. All responses were recorded.

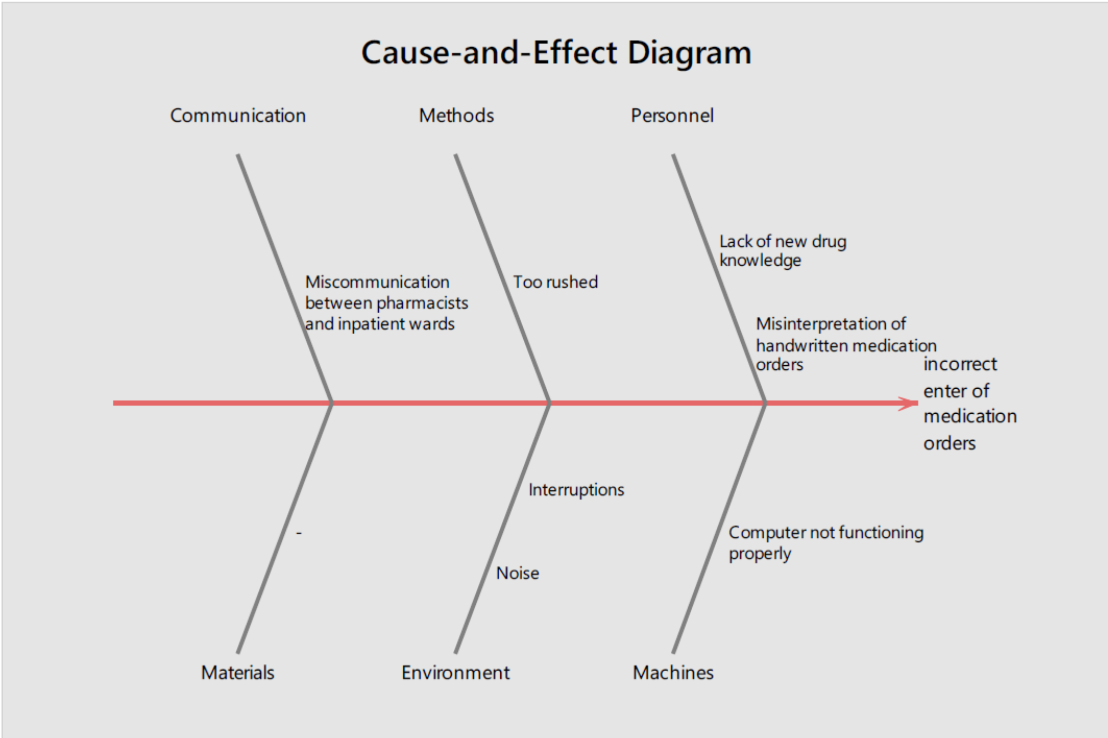

Figure 4. Cause-and-effect analysis of medication order entered incorrectly.

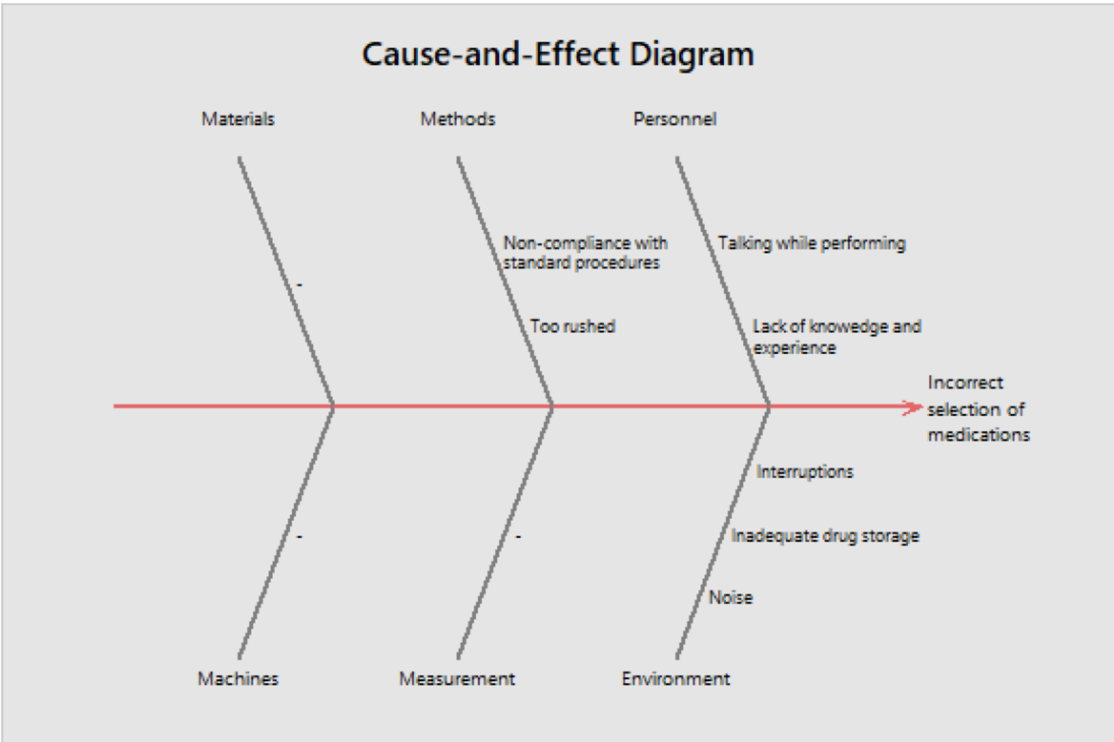

Figure 5. Cause-and-effect diagram of incorrect medications selection.

Causes of incorrect enter of medication orders	1st Why	2nd Why	3rd Why	4th Why	5th Why	Potential solutions
1.Too rushed	Pharmacists received a high number of medication orders from wards.	Lack of screening medication orders to identify whether the medication orders should be immediately sent to the inpatient pharmacy service or not.	Lack of STAT medication delivery guidelines.			Develop a guideline for STAT medications ordering process.
2. Interruptions	There were more prescription orders from the wards after the unit cards had been dispensed to the different wards.	Nurse did not collect medication orders and sent in different round after doctors' ward round.	Lack of criteria for sending medication orders to the inpatient pharmacy service			Develop criteria for nurses to deliver medication orders
3.Misinterpretation of handwritten medication orders	Illegible handwriting of doctors	Copy of prescription orders are unclear (indistinct carbon copies of medication orders).	Nurses not checking the legibility and not clarifying medication orders before sending these orders to the inpatient pharmacy service.			Develop criteria for nurses to follow before sending medication orders to the pharmacy service.

Table 2. 5-Why analysis identifying root causes of entry of incorrect medication orders

Causes of incorrect enter of medication orders	1st Why	2nd Why	3rd Why	4th Why	5th Why	Potential solutions
1.Too rushed	Pharmacists received a high number of medication orders from wards.	Lack of screening medication orders to identify whether the medication orders should be immediately sent to the inpatient pharmacy service or not.	Lack of STAT medication delivery guidelines.			Develop a guideline for STAT medications ordering process.
2. Interruptions	There were more prescription orders from the wards after the unit cards had been dispensed to the different wards.	Nurse did not collect medication orders and sent in different round after doctors' ward round.	Lack of criteria for sending medication orders to the inpatient pharmacy service			Develop criteria for nurses to deliver medication orders
3.Misinterpretation of handwritten medication orders	Illegible handwriting of doctors	Copy of prescription orders are unclear (indistinct carbon copies of medication orders).	Nurses not checking the legibility and not clarifying medication orders before sending these orders to the inpatient pharmacy service.			Develop criteria for nurses to follow before sending medication orders to the pharmacy service.

Table 3. 5-Why analysis identifying root causes of medication orders entered incorrectly

Improve Phase

Once root causes were understood, the team brainstormed potential solutions to minimize root cause effects, after which a two-month solution implementation plan was prepared, inclusive of responsibilities and target completion dates. Solutions were as follow:

1. Redesign the existing daily dose medication preparation process. All medication carts for all wards were prepared on a day-by-day basis, with pharmacy technicians no longer needing advance preparation of medication carts.

2. Develop criteria for nurses to deliver medication orders. Pharmacists secured the cooperation of ward nurses to collect all medication orders after doctors' morning and afternoon ward rounds. The inpatient pharmacy service staff then collected ward medication orders.
3. Develop a STAT medication ordering process guideline. STAT medications must be administered to patients within 30 minutes. Misunderstanding between practitioners involved in STAT medication administration and dispensing resulted in some patients not receiving medication on time, thereby elevating health risk. Since a high proportion of STAT medication orders were sent to pharmacists, the team met with the Pharmaceutical and Therapeutic Committee (PTC) to review and develop a STAT medication ordering guideline for nurses and doctors to follow.
4. Develop standard practices for nurses to follow before submitting medication orders to the inpatient pharmacy service, so that whenever a nurse encounters unclear, incomplete and/or inappropriate medication orders, they must confirm medication orders with the doctor who wrote the original order. After doctor verification, the nurse corrects the medication order details before sending them to pharmacists.

Control Phase

To ensure sustained improvement, the following mechanisms were implemented:

1. Standard operating procedures development:

New daily dose medication preparation procedures were standardized and placed near the pharmacy technicians' workstation. SOPs provided detailed task descriptions, and persons responsible. Inpatient pharmacy staff were trained to use SOPs. Implemented SOPs were evaluated and updated monthly. The inpatient pharmacy head regularly monitored staff to ensure SOPs were followed.

2. Statistical process control implementation:

A P-control chart was developed to monitor the monthly dispensing process, track trends, and detect unusual process behaviour. After intervention implementation, dispensing error proportions were calculated and the chart was updated on a monthly basis. The P-control chart compared the proportion of dispensing errors before-and-after LSS implementation (Figure 6). The average dispensing errors proportion was reduced from 0.0018 to 0.0008. Data was collected over a 10 month period, a period determined by limited hospital access during the completion of the action research and LSS implementation. However, performance of the new process is known to be consistent over time (Al Kuwaiti and Subbarayalu, 2017). A non-parametric statistical hypothesis test was used to compare the number of dispensing errors before and after LSS implementation. In this case study, a Wilcoxon signed rank test was used to compare pre (Mean= 24.50, SD= 7.38) and post (Mean= 8.83, SD= 3.43) LSS implementation. Two groups (n=10) of the number of dispensing errors before and after LSS implementation were taken with a purposive sampling for the comparison. Use of purposive sampling allowed the authors to access a particular data set. Results indicated that following LSS implementation, dispensing errors were significantly decreased ($Z = -2.61$, $p = 0.009$).

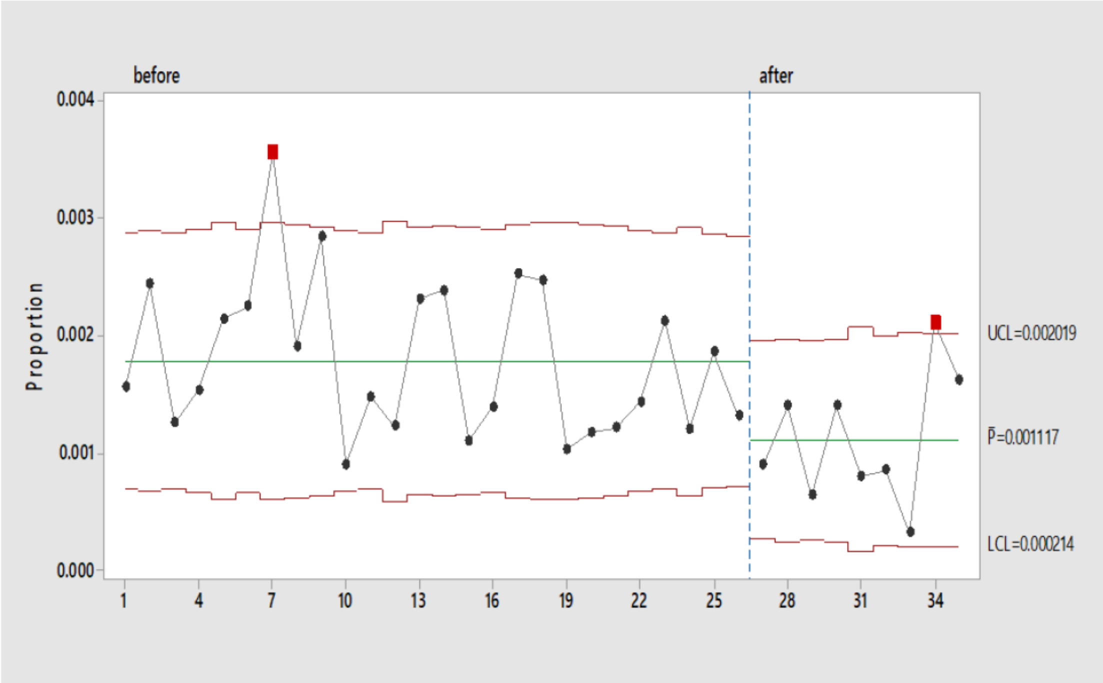

Figure 6. P-chart of dispensing errors before and after implementation

LSS Implementation Challenges

The main LSS implementation challenges resulting included resistance to change and ineffective communication. Although, project team members received training in LSS and its benefits prior to project commencement, remaining inpatient pharmacy staff lacked awareness of how LSS could improve their routine work. Contributing to this was inadequate information-sharing at all inpatient pharmacy levels. Further, pharmacy technician agreement to routine task changes was difficult to secure, as technicians lacked trust and they misunderstood the positive value of change and hence resisted learning new methods, preferring adherence to historic routines instead.

Critical Success Factors for LSS Implementation

Three critical factors facilitated successful LSS implementation: leadership, creativity and problem-solving skills, and middle management support and involvement. Further, time and manpower contributed to the success of the LSS implementation.

Leadership: The Inpatient Pharmacy Head employed a transformational leadership approach to encourage and motivate the project team and to drive LSS initiative success. Key characteristics of this transformational leadership included problem-solving involvement, motivation, open-mindedness, and encouragement.

Creativity and problem-solving skills: The use of creative ideas to generate effective solutions and resolve problems was critical to success. This supports the inherent value in selecting creative team members with appropriate problem-solving ability to execute LSS projects.

Middle management support and involvement: Middle management support consisted of several elements: understanding the need for and benefits of LSS, provision of appropriate project resources, and active involvement in all LSS deployment phases (Psychogios et al., 2012). The Inpatient Pharmacy Head had substantial awareness of LSS, was actively engaged and dedicated in all LSS phases, and provided sufficient time for team members to execute the project.

Discussion

Research Question 1: Is Lean Six Sigma suitable for reducing medication errors in a hospital environment?

Medication errors increase mortality rates, length of stay, and related costs (Cheragi et al., 2013). Several studies have implemented large capital investment and maintenance intensive information technologies including; barcode systems, automatic dispensing machines and automated pharmacy carousel systems to reduce medication errors (Halkin et al., 2001; Oswald and Caldwell, 2007). Such high cost solutions sometimes limit implementation. For example, the general Thai hospital pharmacy practice has not reached its best standard practice due to limited financial support and lack of newer technology (Chaiyakunapruk et al., 2016).

LSS seems to be an excellent choice for hospitals desiring both process and bottom-line improvement. Further, it is useful in reducing medication errors in a hospital when properly applied by a team that includes doctors, pharmacists, nurses, hospital managers, and LSS experts (Honda et al., 2018). Healthcare practitioners have implemented varied improvement approaches to mitigate dispensing errors such as ensuring proper storage of medications, use of Tall Man lettering to emphasize sound-alike medications, adding warning signs for look-alike medications, and promoting good dispensing awareness among healthcare providers (Wittich, 2014; Stefanacci and Riddle, 2016). Despite such improvement approaches, dispensing errors remained, returned and/or could not be resolved. Application of LSS tools in the DMAIC analyse phase can aid detection of root causes of medication process problems, leading to error reduction and process improvement. Such tools are often applicable for complex problems with less than obvious solutions (Edgeman, 2020).

Research Question 2: What are the benefits, challenges, success factors, and key lessons learned from implementation of Lean Six Sigma to reduce medication errors in a Thai Hospital?

Key benefits of LSS implementation in the inpatient pharmacy are: 1) reduced dispensing errors, 2) improved process flow, 3) improved patient safety, 4) improved employee morale, 5) improved communication channels between pharmacists and pharmacy technicians, 6) increased patient satisfaction and 7) reduced medication error cost. LSS implementation reduced process variation, reducing the number of errors undetected by the pharmacists from 29 in March 2018 to 6 in November 2019, an approximate 80% reduction. The number of errors at each process step (e.g. entering medication orders) was also reduced from 351 to 93 during the same period. This reduction in the number of errors shows that the elimination of non-value-added activities during medication preparation can improve medication dispensing process flow. The new daily dose medication preparation process also decreased staff workloads, thereby helping staff to complete tasks more easily. This finding is consistent with Esimai (2005), whose application of Lean Six Sigma reduced medication errors by 58% in a mid-sized hospital. In this study, prevention, detection, and correction of dispensing errors before they affect patients improved patient safety. Elsewhere, hospital implementation of LSS resulted in reduced parenteral medication administration errors and improved morale (van de Plas *et al*., 2017).

Another important benefit of LSS was overall increase in patient satisfaction post LSS implementation. Patient satisfaction with the quality of pharmacy services post-LSS implementation (Mean= 4.38, SD= 0.56) was higher than pre-LSS implementation (Mean= 4.00, SD= 0.45). These results indicate that there was a statistically significant increase in overall patient satisfaction ($p < 0.05$).

It is difficult to calculate the cost of medication errors due to significant variance between each type of error, patient consequence and clinical context (Patel et al., 2016). This study based its medication error cost on the previous studies, which had quantified the economic burden associated with medication errors (Samp et al.,2016). Therefore, it is proposed that the successful implementation of LSS can reduce cost of the relevant drug associated with the error by approximately $89 per error (Choi et al., 2016). This finding is also in line with Hintzen et al. (2009) which showed that inpatient pharmacy hospitals can save $82,650 annually by reducing the number of errors and missing doses.

The primary LSS implementation challenge encountered was insufficient and ineffective communication between departments and between the team and other inpatient pharmacy staff (e.g. inpatient pharmacy and wards). This aligns with earlier studies indicating lack of or poor communication as a major challenge in implementing healthcare industry continuous improvement initiatives (Antony et al., 2012).

Consistent with (Castle et al., 2005), the team encountered resistance from pharmacy technicians with regard to making changes in routine tasks. Resistance is common when established routines must be changed, hence it is critical to clarify the need for change and benefits accruing to all staff involved.

Another major challenge in implementing LSS in healthcare to reduce medication errors is obtaining baseline process performance data (Sehwail and DeYong, 2003; Taner et al., 2007; Antony et al., 2007). Whilst the Thai hospital in this case study stored relevant data, it had never analysed or used this data in problem-solving.

Case study results identified LSS implementation factors critical to medication error reduction. These included leadership, creativity and problem-solving skills, and middle management support and involvement. These have also been reported by Pamfile et al**.** (2002) who indicated that leadership involvement in LSS projects is necessary to motivate and encourage healthcare staff. Although rarely cited in literature, team member creativity and problem-solving ability generates potential solutions and contributes to effective LSS use and implementation.Previous studies indicate appropriate team member identification as critical to successful LSS implementation (Castel et al., 2005; Antony et al., 2007).

Although unsuitable for projects that must be completed within a set time period, action research provided several LSS implementation lessons. Prior to conducting the project, all inpatient pharmacy staff should understand the relevance of LSS relevance and how its application might improve processes. When potential root causes are identified, it is important to establish their relative importance and ensure that implemented corrective actions reduce their impacts. Major dispensing process changes can be straight-forward, without the need for major investment.

Research Question 3: What tools and techniques of Lean and Six Sigma can be utilized to reduce medication errors?

In this project, the majority of the LSS tools and techniques used across the DMAIC methodology were non-statistical, with tool selection based on the problems examined. Trakulsunti et al. (2018) identified the five leading Lean tools used to reduce medication errors as process mapping, spaghetti diagrams, visual process control, standard operating procedures, and poka-yoke. Lean tools selected for application in this project included process mapping, spaghetti diagrams, and standard operating procedures. Poka-yoke was deemed inappropriate for use.

Castle et al. (2005) applied process mapping to a home-delivery pharmacy service in the define phase of the DMAIC, to understand process flow and identify process improvements. In this case study, process mapping and a spaghetti diagram were used in the define phase to identify dispensing error problems. Similarly, a project charter was employed to identify the project's scope and goals. No existing literature indicated use of a define phase project charter in the context of medication errors.

Data collection planning, CTQ characteristics, and control charts were used in the measure phase. This mirrors findings of Antony et al. (2018) in a systematic review of Six Sigma application in healthcare that identified data collection planning, CTQ characteristics, and control charts among the five leading measure phase tools. A P-chart was used to assess baseline dispensing process performance. Literature indicates that control charts have not previously been used in the measure phase to establish current process performance in the context of medication dispensing errors. The P-chart was used to estimate the average proportion of dispensing errors and to monitor whether the dispensing process was in statistical control. The result showed that the average proportion of dispensing errors reduced from 0.0018 to 0.0008, a 55% reduction.

Existing literature identified brainstorming as the most commonly used tool to identify medication dispensing process error causes (Esimai, 2005; Nayar et al., 2016). Whereas no prior studies have applied any tools or techniques to identify root causes of medication dispensing process errors, the current case used five-why analysis in the analyse phase to accomplish this, with cause-and-effect analysis and multi-voting also used. Although gemba and hypothesis testing have been commonly used to identify the root causes in the healthcare sector (Bhat, Gijo, and Jnanesh, 2014; 2016), it is seen herein that due to ease of application, five-why analysis is also useful as it guides the project team to determine and understand root causes of specific problems by encouraging them to generate improvements based on their experience.

Brainstorming is a commonly used improve phase tool because it generates potential solutions (Chan, 2004; Al Kuwaiti, 2016). Brainstorming was used in redesign of the hospital's daily dose medication preparation process, an action consistent with prior findings indicating that redesigning pharmacy work processes can reduce workloads and improve work environments that contribute to dispensing errors (Sanguansak et al., 2012).

Similar to studies using control charts to sustain improvements in the control phase (Chan, 2004; Benitez et al. 2007), control charts and standard operating procedures were used in the present case study. Few studies, however, have graphically presented the control chart. Further, a hypothesis test was used to compare the proportion of dispensing errors before-and-after LSS implementation. In contrast to previous studies, hypothesis tests were also applied during the analyse phase to validate possible root causes identified by cause-and-effect diagrams (Gijo et al., 2013; Bhat, Gijo, and Jnanesh, 2014). No prior studies use hypothesis testing to compare the process pre-and-post improvement, suggesting that hypothesis tests should be included in the control phase to test the proportions of errors before-and-after the improvement.

This study also suggests that simple LSS tools can be used to tackle problems and improve processes in service organizations, particularly in hospitals. Lifvergren et al. (2010) confirmed that use of advanced statistical tools in all DMAIC phases is not required to achieve successful results. In contrast, Bhat, Gijo, and Jnanesh (2014) suggested that both simple and advanced statistical tools are of value in service sectors when team leaders understand how to use LSS statistical tools.

Conclusions and Limitations

Application of LSS to the Thai hospital inpatient pharmacy dispensing process improved the dispensing process, contributed to reducing dispensing errors, and enhanced patient safety. Prior studies have shown lack of understanding in selection and use of LSS tools and techniques in each phase of the DMAIC methodology. This study has provided an opportunity to advance the understanding of tools and techniques and their value in reducing medication errors in various LSS phases. Application of LSS and its tools in the context of inpatient pharmacy dispensing errors has not been previously reported, hence this study is novel and bridges this gap. This study also highlights leadership, creativity and problem-solving skills, and middle management support and involvement as key LSS implementation success factors.

One of the limitations of the study is that it was undertaken in the inpatient pharmacy in a public hospital in Thailand, meaning that the study findings cannot be generalized beyond the specific setting. However, the dissemination of these findings could be applicable to or inform similar contexts or situations. Additionally, the lack of participant awareness of LSS tools and techniques created specific challenges during LSS implementation in the inpatient pharmacy.

Implications

Literature on the use of Six Sigma to reduce outpatient clinic dispensing errors is limited with one case identified (Chan, 2004). However, this paper presents a novel case study which is the first study to apply LSS to reduce inpatient pharmacy dispensing errors in a public hospital. Findings should be of interest to hospitals having the dual aims of improving patient safety and reducing operational costs. Other hospitals could follow this roadmap by employing LSS to reduce errors in every phase of medication use from prescribing, transcribing, and dispensing, to medication administration, with the current study serving to increase hospital senior managers' and medical directors' awareness of the role of LSS and its associated tools (Trakulsunti and Antony, 2018). Outpatient settings and inpatient wards can provide scope for further improvement.

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