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Implementation of Lean and Six Sigma Methodologies to Improve the Operations and Efficiencies of an Inpatient Pharmacy

Brian Ricks, M.S.

Western Michigan University, 2022

Reducing overhead costs and eliminating process waste are important aspects of any successful organization. Hospital processes are frequently interconnected, with many exchanges of both materials and information between departments. The Inpatient Pharmacy, a key component of any hospital, has hundreds of interactions between departments on any given day, and many processes see the pharmacy acting as producers, consumers, and transporters of goods throughout the hospital. Such a varied role provides broad opportunities for process improvement.

Within the broader manufacturing world, the philosophies of Lean and Six Sigma have helped many companies increase their process efficiencies, reduce costs, and increase quality. The end goal of this project is to improve the workflow within the Inpatient Pharmacy process through Lean Six Sigma techniques and provide pharmacies' teams with the tools necessary to enact improvement projects in the future. A study was enacted which observed worker movements within the pharmacy and highlighted future improvement projects. This study identified the highest frequency destinations for pharmacy technicians, and the most frequently traveled routes between workstations. An adjusted facility layout was proposed and adopted which reduces non-valued added movement by at least 15%.

Implementation of Lean and Six Sigma Methodologies to Improve the Operations and Efficiencies of an Inpatient Pharmacy

By

Brian Ricks, M.S.

A thesis submitted to the Graduate College
in partial fulfillment of the requirements
of the degree of Master of Science,
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Lastly, I would like to thank my dear wife, who showed nothing but support for me as I put our small family through yet another round of schooling in pursuit of a dream. For her love and patience, I will always be grateful.

Brian Ricks

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List of Abbreviations

DMAIC

Define, Measure, Analyze, Improve, Control

LSS

Lean Six Sigma

NVA

Non-value-added

IV

Intravenous

ADC

Automated Dispensing Cabinets

Introduction

Lean is a manufacturing philosophy developed by Toyota in Japan following the second world war (*Dekier, 2021*). It focuses on improving process efficiency by reducing waste and is divided into seven categories: defects, overproduction, transportation, inventory, waiting, motion, and extra-processing (*Bharsakade et al., 2021*). These seven wastes are used to broadly categorize areas for process improvement. Another popular process improvement philosophy is Six Sigma, which was developed by Motorola in the 1980s and focuses on controlling and improving the quality of the product or service being delivered (*Motorola University, 2005*). Six-Sigma projects follow a data-driven improvement cycle known as DMAIC: <u>D</u>efine, identification of areas for improvement; <u>M</u>easure, quantifying the area of concern; <u>A</u>nalyze any data collected; <u>I</u>mprove, implementation of plans; and <u>C</u>ontrol, embedding changes for long-term stability (*Ahmed, 2019*). Although Six Sigma was originally conceived by Motorola as a quality control method, the techniques involved have broad applicability for data collection and root-cause analysis (*Vendrame et. al, 2017*). Unification of Lean and Six Sigma philosophies began as early as 1986, with the George Group being the first to integrate the two (*Salah et. al, 2010*). Additional efforts to unify them continued through the 2000's, and today they frequently go hand-in-hand with the idea of process improvement, focusing on improving quality by reducing waste.

Both philosophies use statistical analysis to identify opportunity for improvement in a process, and both have been successfully used in the broader manufacturing world, and to a more limited degree in the healthcare industry (*Niñerola et. al, 2020*). However, the healthcare industry tends to be more conservative with respect to adopting LSS (*Fogliatto et. al, 2019*); (*Zimmerman, 2020*), and a cursory search on PubMed reveals that research into the hospital application of Lean Six Sigma (LSS) practices has only just begun to catch on in the last decade. Approximately 1,500 results were published in the year 2011, which increased year by year, up to 5,500 in 2021. However, Zimmerman (*Zimmerman et. al, 2020*), who provides a more comprehensive review of the state of LSS studies in healthcare, found that, of the 73 full texts they analyzed, 23 were excluded due to failure to apply DMAIC principles, a key feature of Six Sigma projects. This indicates that not all research which purports to use LSS can be relied upon to satisfactorily follow the methodology.

The impetus for this study began during repeated observations of the processes and practices within the Inpatient Pharmacy at a Southwest Michigan Hospital.

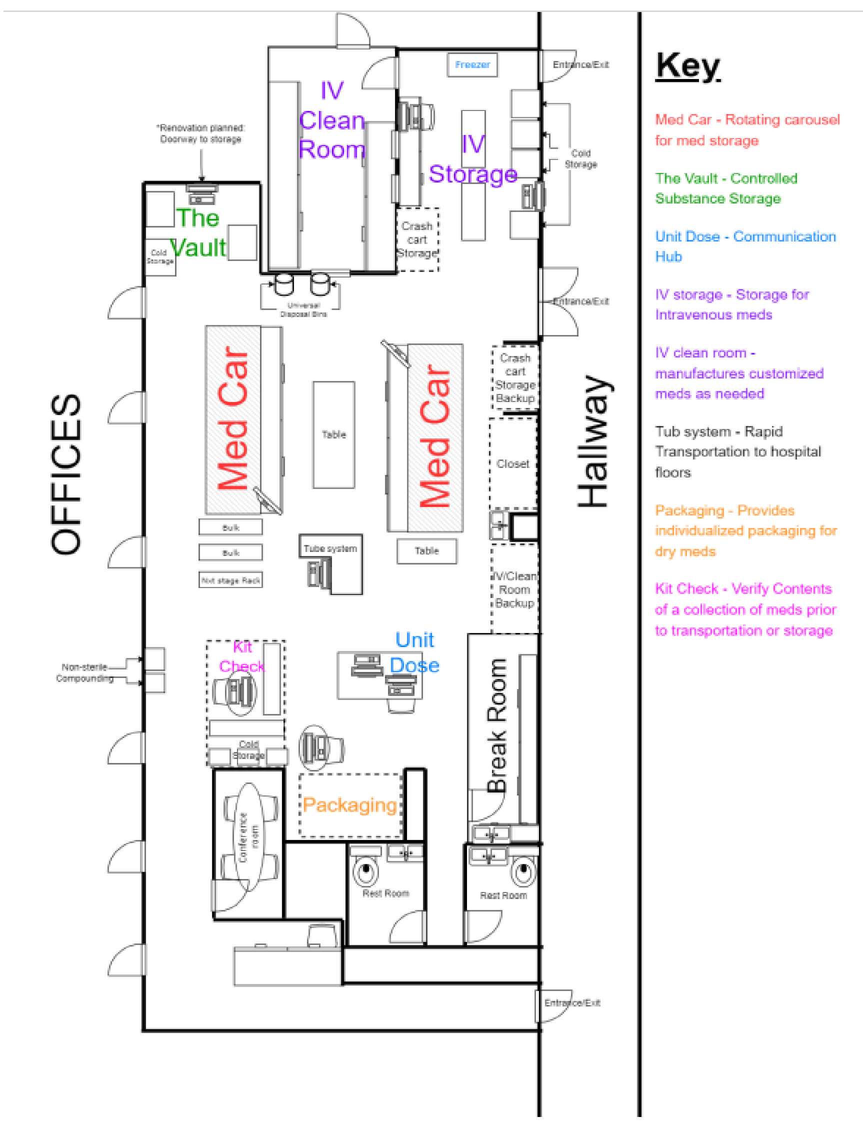

Figure 1 - High Level Schematic

The pharmacy had recently undergone a renovation which resulted in a restructure of the floor plan and saw both the addition and the removal of several large pieces of equipment. Additionally, the hospital suffered a large reduction in staff since the beginning of the COVID-19 pandemic, with only 4 of the 15 Pharmacy technician roles regularly being covered. These challenges prompted the requests for intervention in identifying areas for improvement.

The first step of the DMAIC process helps define those areas for improvement through observation and data collection. Initial observations of the Inpatient Pharmacy were used to Define the operations improvement project by identifying:

1. Pharmacy functions and process,
2. Pharmacy outputs,
3. Pharmacy worker roles, and “customers” (recipients of pharmacy outputs),
4. Mapping basic processes associated with the pharmacy, and
5. Mapping the facility layout and basic workflows.

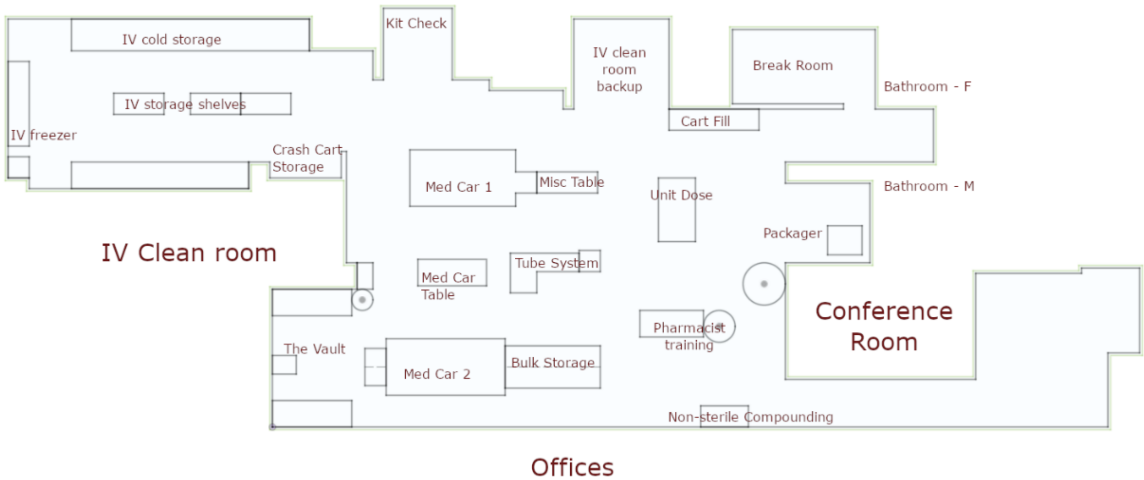

Figure 2 - To-Scale Layout

In Lean Manufacturing, this observation period is called a "Gemba Walk" (*Aji, et.al, 2017*). This was aided by the creation of a high-level schematic of the pharmacy (Figure 1), a to-scale schematic of the pharmacy layout (Figure 2), and several flow charts identifying different processes and the movement of materials (Figure 3 -Figure 6). Two layout schematics were made with Figure 1, representing the observers initial understanding of pharmacy functions and facility layout. Figure 2 represents a to-scale schematic of the pharmacy layout and was used when planning the adjusted layout.

Process Overview

Movement of materials (Figure 3) within the pharmacy occurs as follows: Materials arrive at the pharmacy shipping and receiving room, to be distributed to more specific storage locations. Controlled substances are stored in the Vault. Dry medicines (meds) are stored in the Medicine Carousel (Med Car). Intravenous (IV) meds are stored in either generalized IV storage,

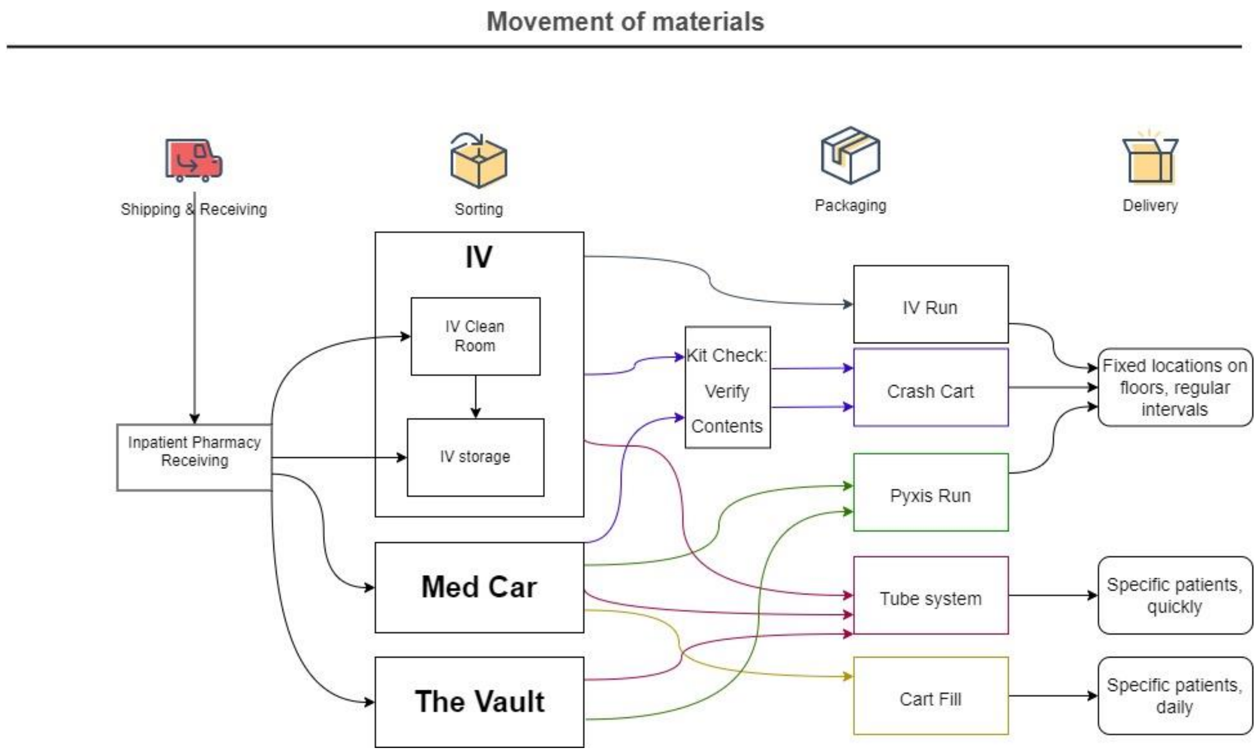

Figure 3 - Movement of Materials

or in the IV clean room to later be mixed into patient specific meds. From these storage locations, items are pulled to fulfill the material requirements of various processes within the pharmacy (i.e., IV Run, Crash Cart, etc.).

The Pyxis Run (Figure 4) is a process by which Automated Dispensing Cabinets (ADC) are restocked throughout the hospital. It begins when the ADC internal inventory

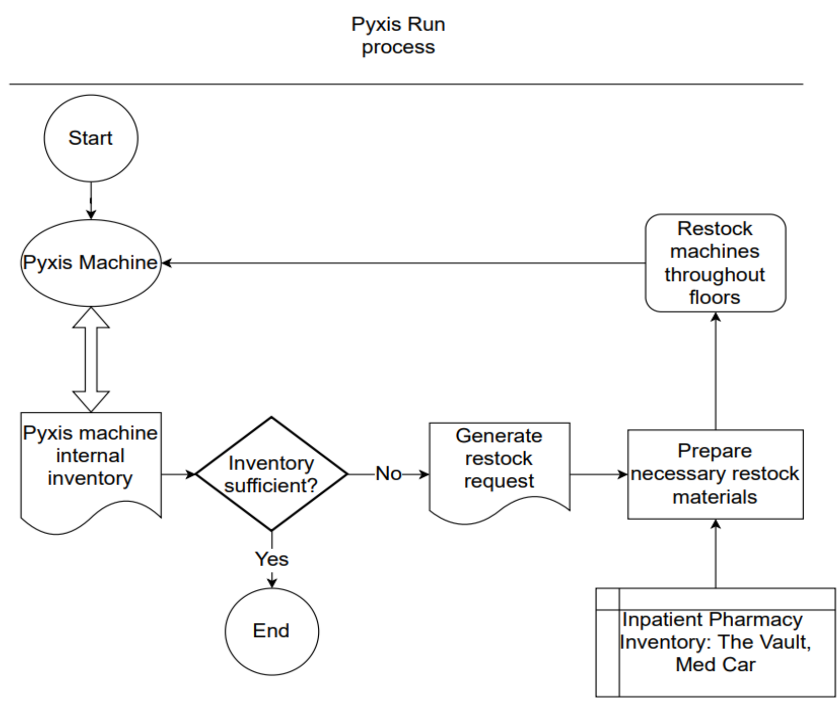

Figure 4 - Pyxis Flow Chart

registers a medicine has fallen below a minimum inventory threshold. That threshold will be unique to each med. Then twice a day, the hospital ADC system will generate a restock request at the Inpatient Pharmacy, listing all the ADC's that are below their threshold, their locations, and the quantity needed. Pharmacy technicians gather the requested meds from pharmacy inventory (the Med Car, or The Vault), then restock the machines throughout the floors, updating inventory counts as they go.

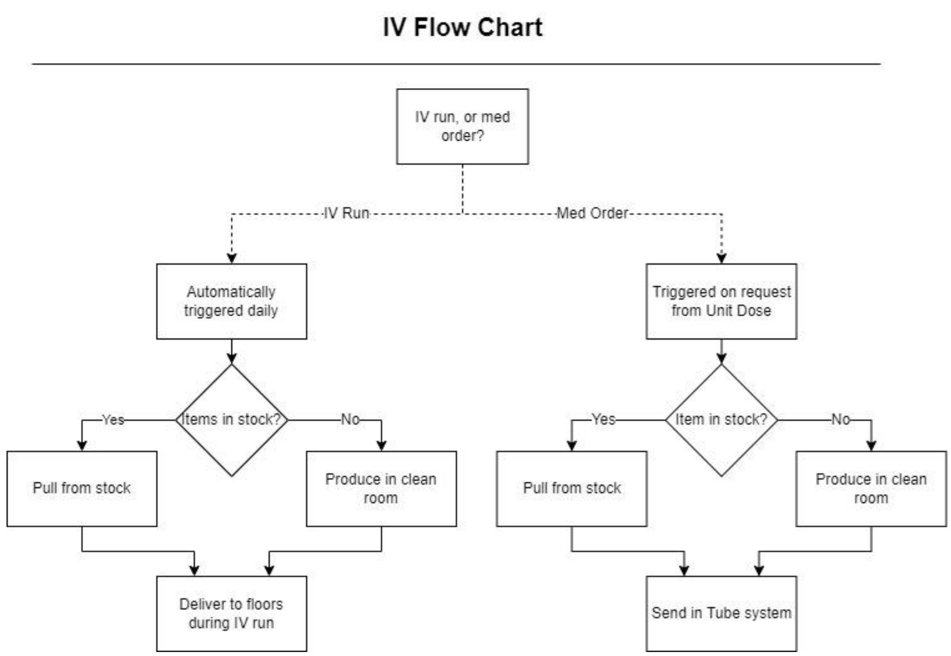

Figure 5 - IV Flow Chart

The Intravenous (IV) section of the pharmacy (Figure 5) deals with the distribution of IV meds throughout the hospital. There are two main processes associated with IV meds; Med Orders, and the IV Run. Med Orders occur when a patient needs a med that is not in stock in the IV cabinets throughout the hospital. If the med is in-stock in the pharmacy, it will be sent up directly via the hospital tube system. The IV Run is analogous to the Pyxis Run process in that it is how IV cabinets are restocked throughout the hospital. IV internal inventory registers when an IV mixture has fallen below a minimum inventory threshold. That threshold will be unique to each med. Then twice a day, the hospital IV system will generate a restock request at the Inpatient Pharmacy, listing all the IV cabinets that are below their threshold, their locations, and the quantity needed. Pharmacy technicians gather the requested meds from IV inventory, then restock the machines throughout the floors, updating inventory counts as they go. For both the IV Run and Med Orders, if the med is not in stock, pharmacists and technicians will work to manufacture it in-house in the pharmacy clean room.

Crash carts (Figure 6) are mobile stations used for transportation of meds for emergency life support protocols in the event of cardiac arrest or other emergent situations. Once used, the carts go to reprocessing for sterilization, then to the pharmacy for material restocking. A ‘not-ready’ sign is attached, indicating that the cart is not yet ready for use. The pharmacy typically has kits pre-prepared to aid in rapid restocking of the crash cart. If pre-prepared kits are unavailable, then materials are gathered from IV and Med Car storage,

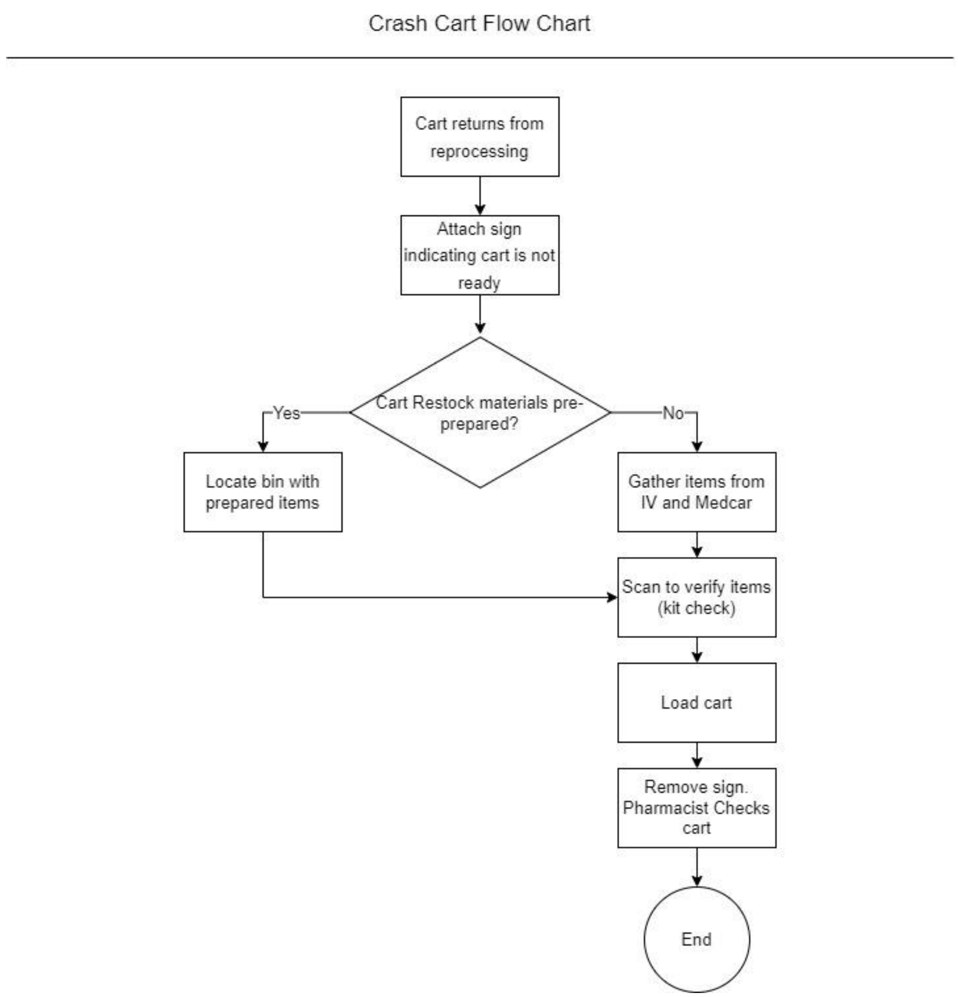

Figure 6 - Crash Cart Flow Chart

and scanned to verify their contents. Materials are loaded into the cart, and a pharmacist does a final verification of contents, removing the 'not-ready' sign upon completion. The cart is now cleared to be placed on hospital floors.

Literature Review

The case study presented in this thesis is only useful in as much as it can find broader applicability in other healthcare departments or institutions. Other studies, such as those carried out by Suman (*Suman et. al, 2021*) or Fogliatto (*Fogliatto et. al, 2019*) have shown the positive impact that the application of LSS techniques can have in improving efficiency in a healthcare setting. Fogliatto specifically shows that planning a facility layout with LSS principles in mind at its inception can lead to significant reductions in waste. However, hospitals constructed before the development of LSS philosophies may not have the advantage of having their facilities planned or optimized in a manner that maximizes efficiencies.

A common theme among LSS related studies in the pharmacy is the reduction in medication errors (*Alkuwaiti, 2016*); (*Chen et. al, 2020*); (*Trakulsunti et. al, 2021*). This is a logical objective, given the potential for harm to patients and financial cost to hospitals due to medication errors. Other studies focused on reduction in patient waiting time (*Arafah et. al 2014*) or increasing process efficiency (*Creed et. al, 2018*). The commonality, though, with all LSS related studies is the ultimate goal of improving the quality of patient care through either reduction in errors or cost savings, or both.

Literature reviews, however, such as those performed by Zimmerman (*Zimmerman et. al, 2020*), presuppose a certain familiarity with LSS practices and provide only theoretical application for the methodologies. A gap exists for the unification of a case study, a literature overview, and a project template. Increased variety in the methods of presenting information may provide the opportunity to educate a broader audience, and this study seeks to fill that gap.

Objectives

The Gemba Walks revealed several opportunities for improvement and cost reduction, covering a variety of topics such as requisitioning new equipment, changing computer login practices, and adjusting the layout of workstations on the pharmacy floor. These opportunities were consolidated by process, with an observed issue or potential cause, thoughts toward improvement, and potential outcomes. A collection of these potential projects was compiled into a project hopper (*Table 1*), a document or series of documents that receives ideas for improvement projects from process stakeholders throughout an organizations hierarchy and helps prioritize the problems or ideas of the organization based on need and feasibility (*Snee et. al, 2002*).

Adoption of any improvement project requires the cooperation and participation of the on-site staff. Following identification of potential improvement projects within the pharmacy, meetings were held to determine interest, timelines, and feasibility with the management team. Ultimately it was decided to Define a project to improve the pharmacy workflow by eliminating waste and improving efficiencies through potential improvements to the pharmacy layout, workstation functions, equipment placement, and worker movements. This was due to a combination of factors, such as time constraints, available tools, and the limited authority to enact changes.

Table 1 - Project Hopper

Process	Opportunities	Initial Thoughts toward Improvement	Potential Outcomes
Unit Dose	Lots of walking between Unit Dose and other station	Move Unit Dose workstation to a more centralized location	Reduce travel time for workers/shorter cycle time on processes
	High frequency of Med requests throughout the day requires a significant portion of work time	Additional training for floor nurses on how to locate meds using Pyxis machines	Increase workforce availability for other tasks
Med Car	Table between the two Med Cars increases travel time between them	Remove the table	Reduce travel time for workers/shorter cycle time on processes
	Removing or adding any item to the Med Car requires employee sign-in	Replace manual password entry with a key card reader	Reduce human error, reduce cycle time
IV	Longer retrieval times for meds, compared to Med Car; reliant on people to find the right med, while many of the meds look very similar	Add a carousel inventory system (might be cost-prohibitive)	Faster cycle time, reduce human error
	Employees report overproduction of custom meds leads to disposal of expired meds	Electronic tracking of IV meds.	Reduce material waste/increased profitability
Packaging	Information must be manually entered; manual entry can be a source for human error, and is time-consuming	Add a scanner to automatically populate the fields	Reduce human error, reduce cycle time, Increase workforce availability for other tasks
Pyxis Restock	Staffing reductions create a big rush at regular intervals; Rush + stress = errors	Add additional employees or assign fewer tasks to each role	Reduce rush, stress, and errors

Excessive worker movement falls under the waste of motion as defined by Lean process improvement. Any motion or travel that does not contribute to providing a service or product is considered a non-value-added (NVA) motion, movement that does not add value to the product or service (*Non-value added, 2022*).

The first objective of this study is to identify and eliminate sources of NVA motion as healthcare technicians move between stations. A secondary objective of this study is: to provide a template for executing a LSS style project, and to show those techniques in practice. Stated simply, this case study is used to:

1. Identify key aspects of LSS methodologies;
2. Provide a template for future applications of LSS;
3. Execute a LSS-style improvement project in an Inpatient Pharmacy.

These objectives serve to motivate further LSS style studies in this hospital specifically, and in healthcare generally. The emphasis is to provide a framework for these techniques to be used not just to solve the issue of inefficient worker movements in the pharmacy, but to adapt the methodology to future studies.

Methodology

Part of the power of methodologies such as Lean and Six Sigma, comes from the skillful application of process improvement tools. The tools used during this study are merely the tip of the proverbial iceberg, and the following is a discussion of LSS tools available during a given project.

DMAIC – The DMAIC process has already been discussed briefly, but to reiterate, it functions as a general guide for the steps of process improvement, with each letter standing for a step in said improvement.

1) <u>Define:</u> Identify a product or process in need of improvement. This should be accomplished by defining the following:
    a. The "problem," or opportunity for improvement;

   b. The outputs of the process; and
   c. The voice of the customer and their needs.

2) Measure: Gather data related to the current state of the process. The kind of data being collected is highly dependent on the process or product to be improved. For example, if the process being improved involves medication errors, it may be an error to collect data on worker movements. The more variables you attempt to track, the more expensive and time intensive your experiment becomes. In short, only collect data on what is necessary. Several common methods of data collection are: interviews, direct observations, surveys, digital tracking, or simulation.
3) Analyze: Examine the collected data to find the root causes of waste and inefficiencies in the operations. A wide variety of statistical analysis tools exist, all ranging in complexity, the discussion of which could be the subject of its own review. However, some of the more common tools include Pareto charts, Fishbone diagrams, Value Stream maps, Spaghetti Diagrams, and relationship charts (sometimes called house of quality) (*Rother, 1999*). Selection of the appropriate analysis tool will vary depending on the needs of the process and the skill of the principal investigator.
4) Improve: Develop, test, and implement solutions to improve processes by reducing waste and increasing efficiencies. The most important aspect of this step, however, is the fact that it is an iterative process. To improve operations, this may need to be completed multiple times, and may include:
   a. Reorganizing workstations activities and functions;
   b. Administrative controls;

c. Additional training for employees;

d. Relocating workstations and spaces; and

e. Creating a new layout within the facility.

5) Control: Implement process controls to sustain the improvements through support of the organization's workers and leadership. Frequently this means extensive documentation of the steps taken to ensure the repeatability of the improvement process, and enforcing the protocols generated during the *Improvement* step.

Integrated with the DMAIC, principally in *Define* step, are the Seven Lean Wastes, which were discussed previously. The categories of waste as defined by lean can help focus the objective of a given improvement project and help achieve a narrow and effective scope.

5S is another Lean productivity technique that focuses on workstation organization (*Omogbai et. al, 2017*). Developed in Japan in the 1970's, the method revolves around the acronym 5S, which in English stands for Sort, Set, Shine, Standardize, and Sustain (*Filip et. al, 2015).* This project utilized certain aspects of 5S in optimizing workstation proximity. However, further studies could be undertaken which more fully explore its specific effectiveness in a pharmacy setting.

DMAIC, Lean Wastes, and 5S are just a small sampling of LSS tools. Table 2 (adapted with permission from *Dempsey et. al, 2021*) includes an expanded coverage of available tools and their outputs in the context of LSS.

To involve the hospital administration more fully in the process, a project charter was created, which, as mentioned in Table 2, serves to clearly identify the goals and scope of the project. That charter is included here for reference as Figure 7, omitting personal names and dates. A project charter may also include data collection plans and schedules.

Table 2 - LSS Tools

Title of Improvement Tool	Definition	Outputs
Project Charter	A project charter is used to define the problem statement and attain baseline data for the project.	This is useful in clearly identifying the goals of the project and what was in scope
SIPOC	Suppliers, inputs, processes, outputs, customers (SIPOC) is a tool that summarizes the inputs and outputs of one or more processes in table form	This provides a simple and high-level view of the process and its elements
CTQ	Critical To Quality Tree	Identifies the needs and drivers of the stakeholders and/or process that is critical to achieving quality
RACI	Responsible, accountable, consulted, and informed (RACI)—identifies which stakeholders were responsible, accountable throughout the DMAIC and which stakeholders needed to be kept informed or consulted	This table defines and maps out the roles and who is responsible for each action item
IPO	Input-Process-Output—associated with a diagram that visually represents the process with inputs shown on the left and outputs shown on the right.	
Gemba	Comes from the Japanese phrase 'genchi genbutsu' meaning go and see and specifically means 'the actual place'	A Gemba is where the actual place where the process takes place in the workplace is observed
Ishikawa diagram, also known as a Fishbone diagram	A visualization tool for categorizing the potential causes of a problem. This tool is used to identify a problem's root cause, a Fishbone diagram combines the practice of brainstorming with a type of mind map template to determine cause and effect	To determine the cause and effect of a problem
5 Why's	5 Why's root cause analysis asks the question 'why' as many times as necessary to identify why a problem has occurred or what the root cause is.	To identify the root cause of a problem
FMEA	Failure mode and effect analysis is a systematic, proactive method for evaluating a process to identify where and how it might fail and to assess the relative impact of different failures.	To identify the parts of the process that are most in need of change
Control Plan	A live document that outlines the methods taken for quality control of critical inputs to deliver outputs that meet customer requirements.	Provided a written description of the measurements, inspections, and checks put in place to control each stage of the process

Adapted with permission from Dempsey et al. 2021

For this project, a time study was executed in which the technician roles were observed over the course of 27 hours, for the purpose of capturing movements over the course of an entire shift for each of the 4 observed roles. A time study is a tool for recording worker actions, and what they focus their time on.

Figure 7 - Project Charter

Improve Operations and Efficiency of Inpatient Pharmacy

Area Impacted	**Inpatient Pharmacy**	Process impacted	**Employee Movements**
Green Belt		Telephone Number	
Lean Six Sigma Master Black Belt Mentor		Process Owner (Sustain and Spread)	
Champion (removes barriers)		Hospital/Site	
Start Date		Target Completion Date	

Element	Description	Team Charter
1. Process	Define the process in which opportunity exists.	Movement of materials, personnel, and information may be improved
2. Project Description	Describe the project's purpose and overall objective.	Improve inter-workstation travel times, workstation task times, and distribution of workloads in the Inpatient Pharmacy through adjustment to the floorplan/layout of workstations
3. Project Scope	Define the part of the process that will be investigated.	In scope: Investigate inter-workstation travel times, workstation task times, and distribution of workloads in the Inpatient Pharmacy. Out of scope: Expiring meds, new staff, addition of new tools/equipment, any process outside of the inpatient pharmacy
4. Objective	Define the baseline, the theoretical (ideal) target and the stretch goal for improvement on the primary metrics: Rolled Throughput Yield, Cost of Non-Conformance and Capacity / Productivity.	(see objective table below)
5. Business Results: (in dollars)	Define the improvement in business performance (e.g., sales and income) that is anticipated and when.	Increase Productivity, Lower medication delivery times, Reduced operating expenses
6. Team Members	Define the team members.	
7. Benefit to External Customers:	Define the final customer, the benefit they will see and their most critical requirements.	**Patient:** Shorter wait times for medications, lowered cost **Employees:** Improved work efficiency, reduced fatigue due to wasted movement
	D - Define	**Project Start**

	Baseline (Current state)	Theoretical Future State	Stretch Goal	Units
Productivity (task time:travel time ratio)				
Med delivery time				**Minutes**
Employee Operating Expenses				**$**

8. Schedule	M – Measurement	**Current state (data collection)**	
	A – Analysis	**Data Analysis**	
	I – Improvement	**Implementation**	
		Future State (data collection)	
		Data Analysis	
	C – Control	**Completion (sustain and spread)**	
	Note: Schedule appropriate Safety Reviews.	**Project Completion**	
		Safety Reviews	**Daily** safety review throughout duration of project
9. Support Required	Define any anticipated needs or any special capabilities, hardware, trials, etc.	Providing opportunity for observation of workers and tasks, allowing employees to be interviewed, and executing limited relocation of workstations. Providing opportunities for progress report meetings	

Champion <name> ________________ **Committee** <name> ________________

Process Owner <name> ________________ <name> ________________

<name> ________________

<name> ________________

For this study, when a worker changes workstation the observer recorded both start time and location, as well as end time and location. The roles observed were as follows:

- Unit Dose (U1): responsible for responding to medicine requests and medicine orders from nurses throughout the hospital;
- Pyxis (PX1 & PX2): responsible for delivering medicine from the Inpatient Pharmacy to Automated Dispensing Cabinets throughout the hospital; and
- IV (IV1): responsible for sterile compounding of Intravenous medicine and preparing to deliver to IV cabinets throughout the hospital.

Workstations were assigned a numerical designation for rapid identification during data collection (Table 3). Subject roles were chosen based on staffing availability and were randomized by the hour to reduce the effect the operator or shift might have. Observations were restricted to day shift, primarily because day shift has the highest task requirements and highest traffic. Any changes to the layout would have the largest impact on the day shift, and consequently, the largest impact on excessive, NVA motion. An underlying assumption, however, is that the impact on the night shift is either positive, or of negligible impact in comparison to the high traffic that occurs during the day shift, if negative. A follow-up study may be necessary to identify opportunities for improvement in the night shift. Following the time study, the route data was used to identify:

- Total travel time;
- Average route travel times;
- Destination frequency;
- Route frequency; and
- Total time spent per station (task time).

Table 3 - Workstation ID

Station name	Code
IV clean Room	1
IV storage shelves	2
IV check station	3
IV freezer	4
IV cold storage	5
The Vault	6
Med Car table	7
Crash Cart Storage	8
Pyxis Carts and disposal bins	9
Bulk Storage	10
Tube system	11
Misc. Table	12
IV clean room backup	13
Non-sterile compounding	14
Pharmacist training	15
Unit Dose	16
Cold Storage	17
Packaging	18
Break Room	19
Restroom	20
Pyxis Machine	21
Exit	22
Offices	23
Cart Fill	24
Closet	25
Tube computer	26
Kit check	27

Following the identification of key routes, high frequency paths, and the key relationships between workstations, options for layout adjustment were explored (Figure 8). An optimized layout was developed and presented to pharmacy administration for approval. The redesign focused on identifying the physical difficulty in moving stations, assigning a rating to them based off that evaluation, then balancing the difficulty in relocation with the potential for reduction in wasted movement. The new layout relocated U1's workstation from 16 to 12. Upon acceptance by the administration, the new layout was implemented. Movement data for the affected roles was collected for verification that the applied changes have a statistically significant effect on worker movements using a t-test.

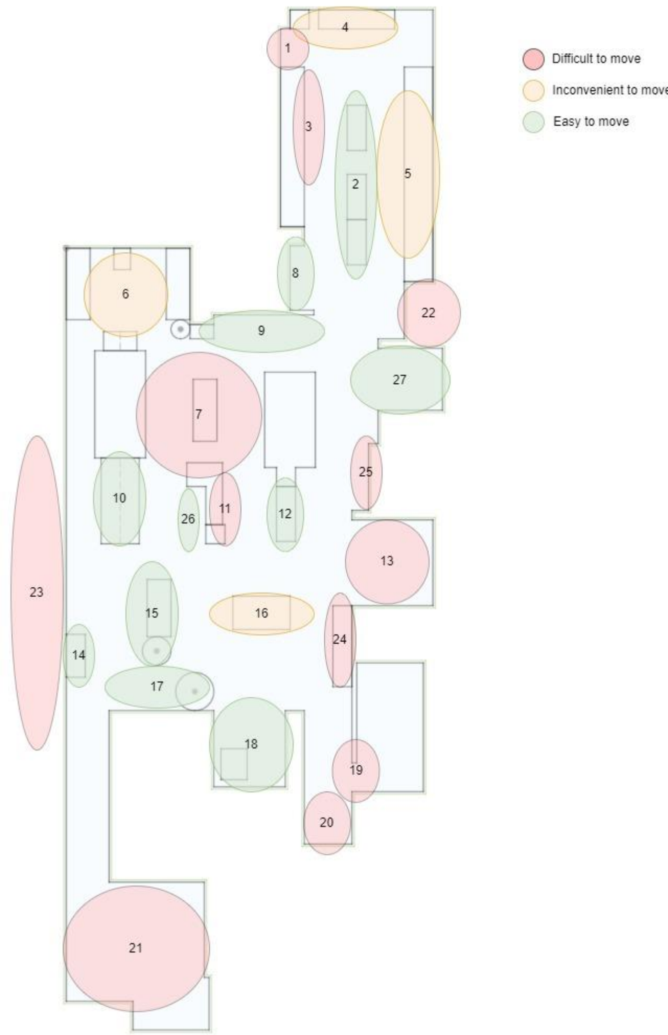

Figure 8 - Workstation Relocation Evaluation

Results

During observation of the four identified and regularly staffed technician roles, nearly 1 hour and 10 minutes were spent traveling between stations. Based on the data collected, 4.25% of workers' time in the pharmacy is spent moving between stations (travel %), i.e., engaged in NVA work.

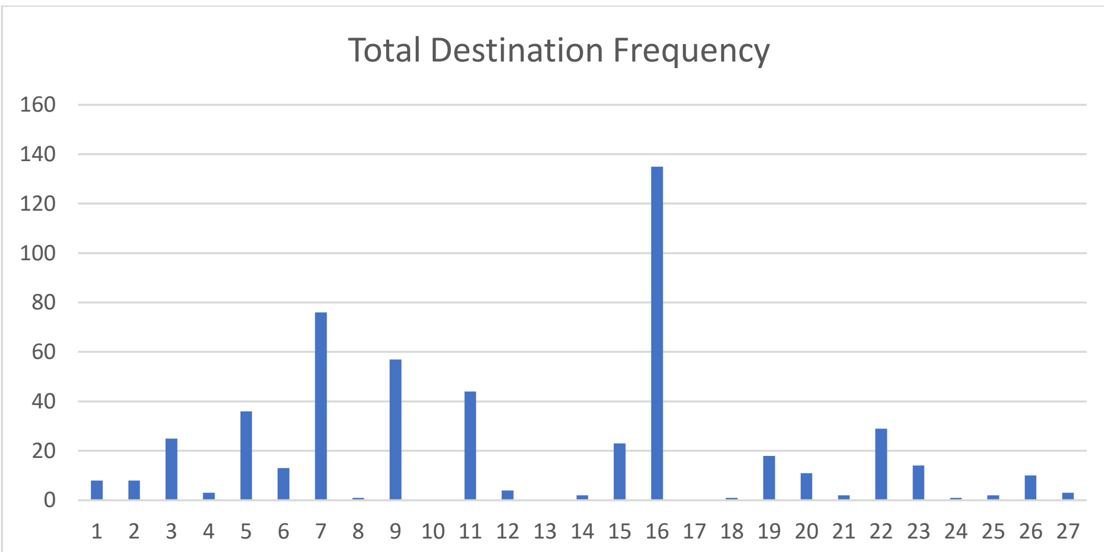

Figure 9 - Destination Frequency

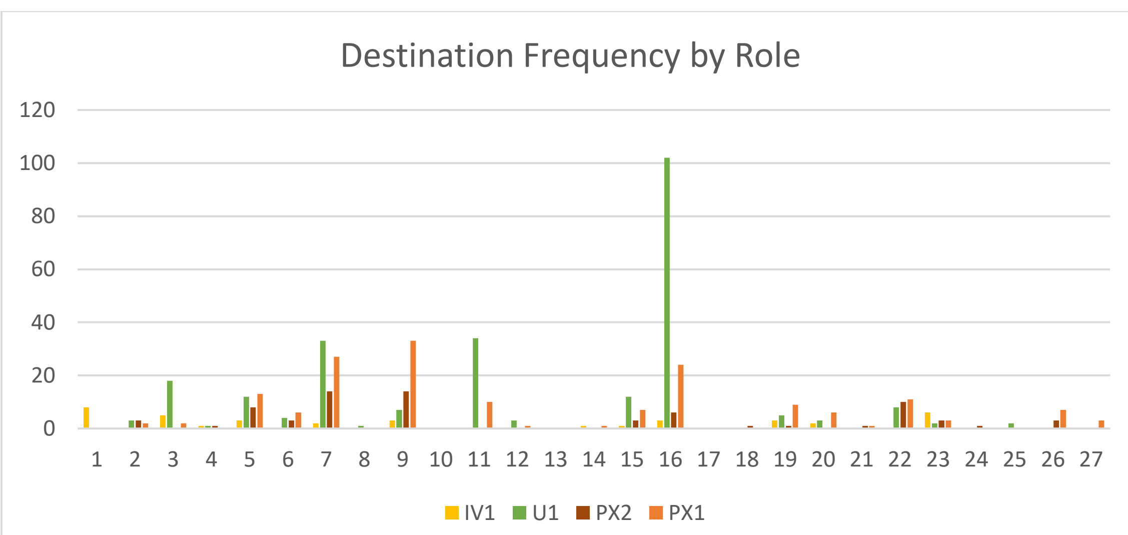

Figure 10 - Destination Frequency by Role

Figure 9 and Figure 10 show that the most frequent destinations for the technician roles during data collection were station 16, station 7, station 9, and station 11, with station 16 being the most common destination by far.

Table 4 - Frequency and Travel % Summary

	U1	IV1	PX1	PX2
Travel %	10.7%	1.3%	4.0%	2.2%
Journeys per hour	47.4%	5.9%	20.9%	12.5%

When subdividing by role, we see in Table 4 that the U1 role made the greatest number of discrete journeys between stations within the pharmacy (with journey being defined as an instance of direct travel between two workstations), as well as the greatest amount of time spent traveling, with 10.7% of their time within the pharmacy spent in NVA movement.

Heat maps were created to help identify which routes had the highest impact on NVA time (Table 5 – Table 8). Routes are denoted by two workstation ID's (Table 3) and represent the path between the stations, e.g. the route between station 1 and station 2 is denoted as 1-2 (or 2-1). A heat map is a data visualization tool which assigns certain colors to data relationships in 2 dimensions. Table 5 shows which routes are associated with highest NVA movement and shows how much time was spent on those routes during observation. Table 6 shows the average travel time of each route while Table 7 shows the standard deviation of the travel time of each route. Table 8 shows the frequency each route was observed to be traveled during the course of the observations. The heat maps confirmed that station 16 experienced the highest density of traffic. Specifically, the routes 7-16 and 11-16 experience the highest traffic, with 3-16, 5-16, 5-9, and 7-9 warranting attention (Table 8).

Table 5 - Total Time traveled (seconds)

Total Time traveled (seconds)																											
Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	-		9		14				81																		
2		-	2				9		17							68						2		9			
3			-	5	80	33	86		13					30		309			15				13				
4				-			8									17							24				
5					-	8	30		131							247				25		7		11			13
6						-	22		12							55			16							60	
7							-		93		58			5	32	450			18	37		39	42			2	8
8								-								17											
9									-		28			8	77	140			14	54		160	46			10	10
10										-																	
11											-				19	209			12	13		39	20				
12												-				22						7					
13													-														
14														-									5				
15															-	57		5	10	15	10	7					18
16																-			76	149	37	95	37		20	25	7
17																	-										
18																		-			10						
19																			-	20		54	27			11	
20																				-						16	
21																					-						
22																						-	57				
23																							-		30		15
24																								-			
25																									-		
26																										-	
27																											-

Low Density High Density

Table 6 - Average Route Time (seconds)

Average Route Time (seconds)																											
Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	-		5		14				41																		
2		-	2				3		3							14						2		9			
3			-	5	13	11	11		7					30		13			15				13				
4				-			8									17							24				
5					-	8	6		7							11				25		3		11			13
6						-	4		2							9			16							30	
7							-		4		5			5	5	10			9	12		5	10			1	8
8								-								9											
9									-		9			8	13	9			14	13		11	23			3	10
10										-																	
11											-				4	4			12	13		13	7				
12												-				4						7					
13													-														
14														-									5				
15															-	3		5	5	15	10	7					18
16																-			6	30	18	11	7		5	4	7
17																	-										
18																		-			10						
19																			-	4		11	13			11	
20																				-						16	
21																					-						
22																						-	28				
23																							-		30		15
24																								-			
25																									-		
26																										-	
27																											-

Low Density High Density

Table 7 – Route Travel Time Standard Deviation (seconds)

Route Time Standard Deviation (seconds)																											
Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1			00.71						23.33																		
2									00.55							03.21											
3					17.64	08.72	01.04									02.21											
4																											
5							02.04		03.43							02.93											
6							04.56		00.49							01.94											
7									01.15		02.66				02.04	08.86				02.08		02.64	05.51			02.52	
8																											
9															09.13	04.22				01.29		09.91	14.14			02.75	
10																											
11															01.64	01.51						03.00					
12																01.37											
13																											
14																											
15																01.00											
16																			02.61	00.00		03.28	03.21		02.16	01.27	
17																											
18																											
19																						02.77	03.54				
20																											
21																											
22																											
23																											
24																											
25																											
26																											
27																											

Table 8 - Route Frequency (All Roles)

Route Frequency (All Roles)																											
Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	-		2		1				2																		
2		-	1				3		5							5						1		1			
3			-	1	6	3	8		2					1		23			1				1				
4				-			1									1							1				
5					-	1	5		20							23				1		2	1	1		1	1
6						-	5		7							6			1							2	
7							-		23		12			1	6	59			2	3		8	4			3	1
8								-								2											
9									-		3	1		1	6	15			1	4		15	2			4	1
10										-																	
11											-				5	59			1	1		3	3				
12												-				6						1					
13													-														
14														-									1				
15															-	19		1	2	1	1	1					1
16																-			13	5	2	9	5		4	7	1
17																	-										
18																		-			1						
19																			-	5		5	2			1	
20																				-						1	
21																					-						
22																						-	2				
23																							-		1		1
24																								-			
25																									-		
26																										-	
27																											-

Low Density — High Density

Table 9 - Relocation Decision Matrix

Station	Frequency	Weight	Importance
1	8	1	8
2	8	3	24
3	25	1	25
4	3	2	6
5	36	2	72
6	13	2	26
7	76	1	76
8	1	3	3
9	57	2	114
10	0	3	0
11	44	1	44
12	4	3	12
13	0	1	0
14	2	3	6
15	23	3	69
16	135	2	270
17	0	3	0
18	1	3	3
19	18	1	18
20	11	1	11
21	2	1	2
22	29	1	29
23	14	1	14
24	1	1	1
25	2	1	2
26	10	3	30
27	3	1	3

Discussions with pharmacy management while considering Figure 8 led to the decision to relocate U1’s workstation from location 16 to location 12. This was accomplished through a decision matrix (Table 9) that assigned a weight to each station which corresponded to its relative difficulty to relocate, with 1 being very difficult to move, 2 being moderately difficult to move, and 3 being very easy to move, represented visually by color in Figure 8. These values were generated following discussions with the pharmacy administration. Multiplying the weight with the destination frequency from Table 9 provided a picture of which stations are of critical “Importance” to pharmacy functions as well as identifying which stations are most easily moved with minimal negative effects to pharmacy workflows. Station 12’s function was an all-purpose worktable/storage. However, it was seldom used, as seen by both its frequency as a destination, and its high proximity to stations critical to U1’s tasks (stations 3, 5, 7, 9, 11), which made it a good candidate for relocation. Additionally, other workstations posed significant challenges to relocation. For example, the tube station (station 11) could not be moved without expensive renovations to the Inpatient Pharmacy.

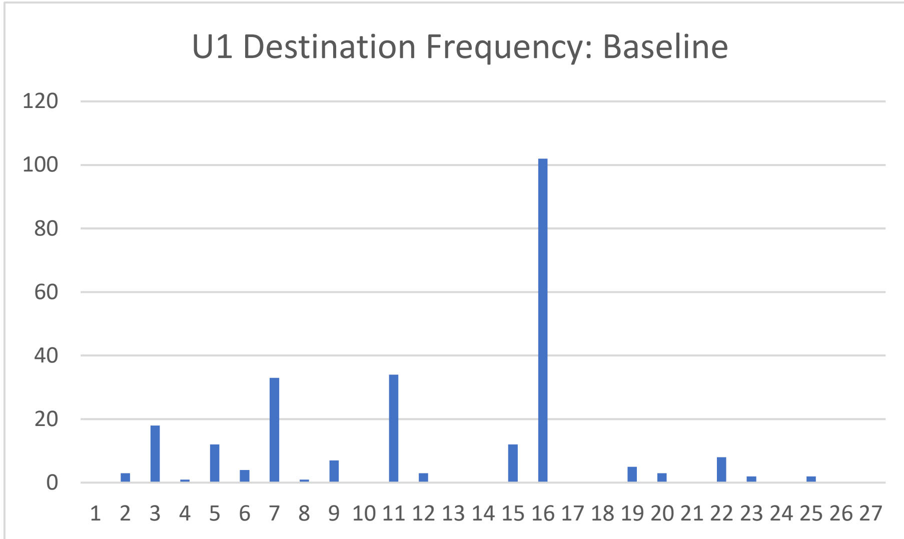

Figure 11 - U1 Destination Frequency: Baseline

The proposed changes were adopted and follow-up data collection for verification of improvement was completed. Due to the higher impact on U1's workflow, follow-up observations focused on U1's movements. The workstation frequency remained similar between the baseline and the improved layouts, with the major exception being station 11 was largely eliminated as a destination, and station 16's destination frequency was transferred to station 12 (see Figures 11 and 12). This transfer was predicted, due to the shifting of station 16's functions to station 12.

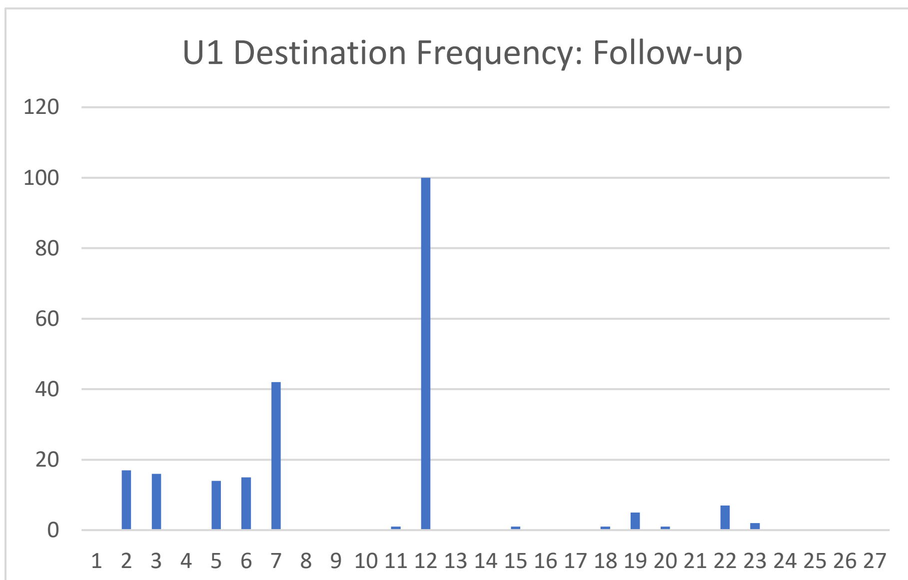

Figure 12 - U1 Destination Frequency: Follow-up

Table 10 - U1 Follow-up Average Route time (seconds)

U1 Follow-up Average																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	-																										
2		-	02			06	05					08															
3			-		04	09	05					09															
4				-																							
5					-	07	04					09															
6						-	04					07										08					
7							-				02	03															
8								-	00																		
9									-																		
10										-																	
11											-	01															
12												-			02			05	04	08		07	06				
13													-														
14														-													
15															-												
16																-											
17																	-										
18																		-									
19																			-	03		10					
20																				-							
21																					-						
22																						-					
23																							-				
24																								-			
25																									-		
26																										-	
27																											-

Low Density High Density

Average Route Time for the U1 role was collected and presented in Table 10. A t-test was performed on high frequency routes, specifically the routes between Unit Dose to Med Car (7-16 and 7-12 for the baseline and follow-up, respectively), and Unit Dose to IV storage (5-16 and 5-12 for the baseline and follow-up, respectively), which showed a statistically significant difference (reduction) in route times (Table 11 and Table 12). Calculating the F-statistic (Table 13 and Table 14) also showed a statistically significant difference (reduction) in the variances. Additionally, when calculating the total time engaging in NVA movement, the data indicated that the U1 role spent only 4.5% of their time moving between stations, compared to 10.7% before adjusting the pharmacy layout.

Table 11 - T-test for Difference in mean route times: Unit Dose to IV storage

	N	$\tilde{x}$	s	T-stat	T-Crit	P-value
Baseline	22	10.8 seconds	2.93 seconds	2.0912	2.0369	0.006523
Follow-up	22	8.73 seconds	1.52 seconds			

Table 12 - T-test for Difference in mean route times: Unit Dose to Med Car

	N	$\tilde{x}$	s	T-stat	T-Crit	P-value
Baseline	59	7.63 seconds	8.86 seconds	4.0733	2.00099	0.00014
Follow-up	76	2.91 seconds	.91 seconds			

Table 13 - F-stat for Difference in variance in route times: Unit Dose to IV storage

	N	$\tilde{x}$	s	F-stat	F-crit	P-value
Baseline	22	10.8 seconds	2.93 seconds	3.7189	2.084	.002007
Follow-up	22	8.73 seconds	1.52 seconds			

Table 14 - F-stat for Difference in variance in route times: Unit Dose to Med Car

	N	$\tilde{x}$	s	F-stat	F-crit	P-value
Baseline	59	7.63 seconds	8.86 seconds	94.477	1.497	1.39E-52
Follow-up	76	2.91 seconds	.91 seconds			

Discussion

The movement of pharmacy workers within the baseline layout (prior to any changes) showed that the U1 role engaged in the highest frequency of movements between stations. It does bear mentioning that when the PX1 and PX2 roles were outside the pharmacy (at station 22) they were traveling between different stations throughout the hospital, so the total time spent traveling may be somewhat misrepresented in the final results. However, this case study was focused on movement in the Inpatient Pharmacy.

In the baseline layout, travel between station 16 and all other stations accounted for 41% of the NVA movement. The projected changes indicated that these improvements to the pharmacy layout would reduce the travel distance of route 11-16 by relocating U1's workstation from station 16 to station 12, to be within the immediate work area of station 11, and effectively eliminating its travel time. Route 7-16's travel time would be reduced by approximately 4 seconds (40% of the total travel time) per journey, leading to an overall reduction of over 10 minutes for all related routes, and accounting for improvements across all roles. When accounting for the effect of travel time to other stations, this represents nearly a 15% reduction in NVA time caused by unnecessary worker motion within the pharmacy, and a 35% reduction for the U1 role specifically. Additionally, while the goals of Lean manufacturing are to reduce waste, Six Sigma aims to reduce variance. Tables 13 & 14 show that the routes from Unit Dose to Med Car and IV storage have less variability in their journey time. This can be beneficial to a hospital because a patient is less likely to suffer adverse effects from the slow delivery of a medication, or variability in delivery time.

After implementing the layout changes, U1 NVA movement was reduced from 10.7% down to 4.0% of their working time. This represents over 60% reduction in NVA work for the U1 role specifically and is better than the projected reductions indicated. The cause for this difference could be attributed to variance between operators, which was not tracked in order to protect privacy. Regardless, the changes to the pharmacy layout show a clear reduction in NVA movement, and an improvement to process efficiency in the pharmacy.

However, work intensification is a possible side effect of improving process efficiency (Stanton et. al, 2014), and can increase worker mental and physical fatigue, which can in turn lead to a reduction in quality. Reductions in quality or efficiency would have an effect opposite to the intended outcome of this case study. However, the scope of this study provided limited opportunities for an investigation of work intensification in terms of observable variables, time, and observers. An important question to consider in a follow-up study could be “Does this improvement in process efficiency lead to work intensification?” More comprehensive studies should endeavor to account for the potential negative effects that changes to established processes may incur. Interviews with pharmacy technicians engaged in specific roles could illuminate the effects of physical and psychological fatigue, both before and after implementing changes to processes. Stanton (*Stanton et. al, 2014*) indicated that there is variability in the outcome of LSS improvement, with regards to work intensification. Some implementations can be positive for some workers, and negative for others. This case study, however, aimed to reduce the physical task requirements of pharmacy worker through layout improvements. It is our belief that the implemented changes are, from a macroscopic viewpoint, relatively minor, and that the positive effects of this case study outweigh its negatives.

Limitations and Future studies

In any research project there exists the possibility of improving some aspect of its experimental design, and this study is no exception. This study only covered the movements of technicians' roles, not pharmacists. The discrepancy in pay scale between pharmacists and technicians could warrant further investigation into optimizing the layout to better suit pharmacists, though anecdotal observation during baseline data collection indicated that pharmacists move between workstations at a rate far below that of technicians. Additionally, pharmacists occasionally covered roles typically fulfilled by technicians. A study could be executed which identifies the frequency in which pharmacists are required to act in technician roles, potentially revealing and quantifying the gap between pharmacy task requirements and pharmacy employee capacity. On a practical consideration with regards to the data collection, the baseline data was collected by a single observer entering times and workstation codes by hand. This human element led to occasional missed movements or journey timings. Video surveillance to track timings could remedy this issue but was not possible for this study due requirements to acquire permission to record from the hospital combined with time limitations on the study.

Another opportunity for follow-up research is in workstation task division efficiency. This study focused solely on improving efficiency through reducing NVA worker movements, while ignoring the tasks that said workers were executing at their workstations. Further improvements to efficiency would require investigating the rebalancing of tasks between the workstations. Many other improvement opportunities were identified during the *Define* step and are catalogued in the project hopper (Table 1).

Conclusion

Lean and Six Sigma techniques have broad applicability in healthcare settings, affording the possibility of significant cost savings and improvements in operational efficiency. This case study showed that even when a LSS project is small in scope, it can have a measurable positive impact in terms of improved efficiency, as seen by the reduction in NVA movements. Recall, the objectives of this study were to:

- Provide a template for future application for LSS. The actions taken during this study led to the creation of a template, seen in Figure 13. To reiterate, the emphasis of this work was to provide a framework to be used not just to solve the issue of inefficient worker movements in the pharmacy, but to adapt the methodology to future studies. Additionally, tools that are commonly used, but were ultimately not necessary for this study, were provided in Table 2. The processes identified in this study may be generalized and applied to other healthcare disciplines because the methods applied here are not exclusive to this hospital. Documenting a phenomenon before and after implementing process changes is simply part of the scientific method.

  The template (Figure 13) may be used as follows:

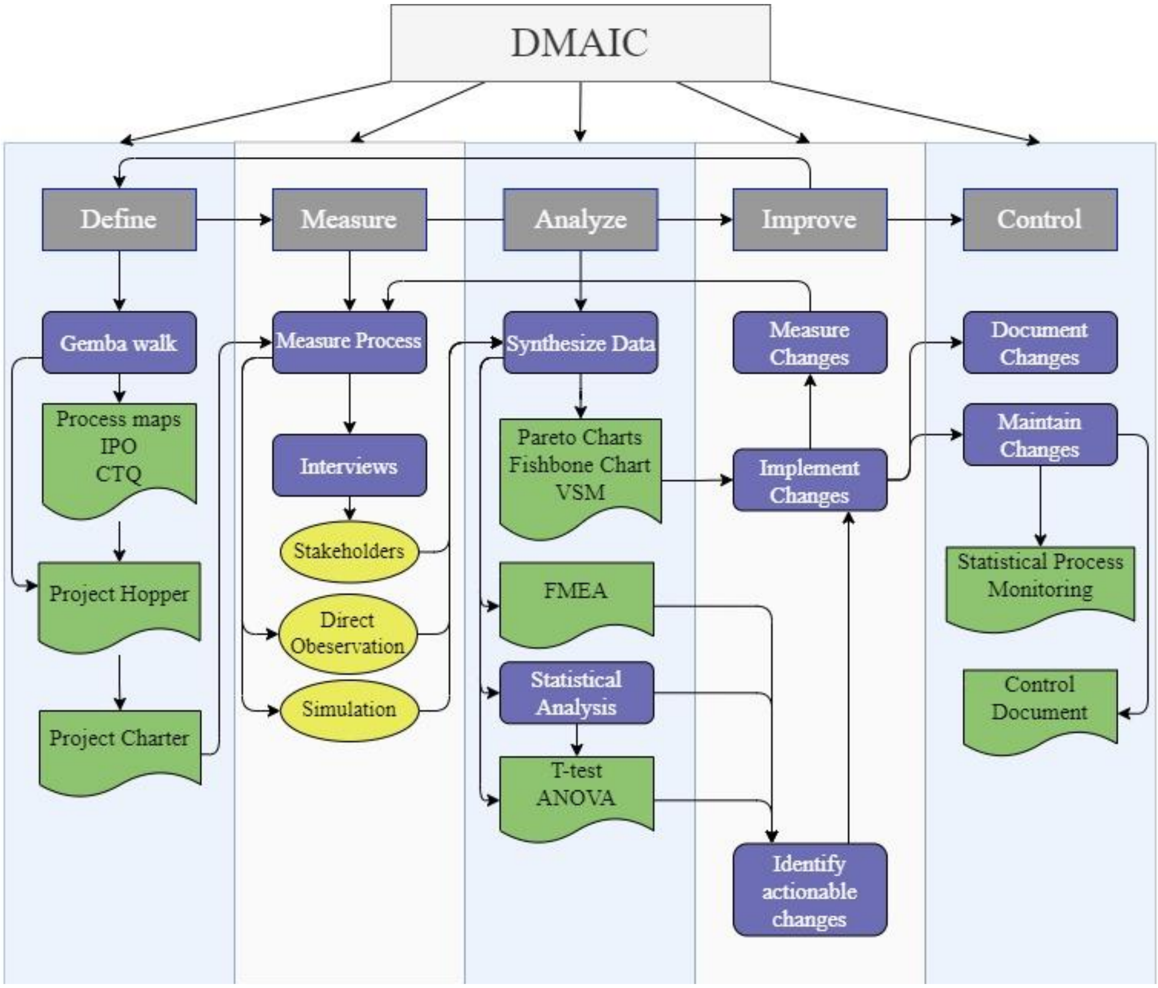

Figure 13 - LSS Template

1. Define the objectives. Identify areas for improvement by observing the product/process through a Gemba walk. Clarify interactions through process maps, IPO and CTQ identification (see Table 2). Summarize improvement opportunities in a Project Hopper. Delineate preliminary objectives with a Project Charter;
2. Measure the product/process. Establish baseline values for areas of interest. Collect pertinent information via direct observation, simulation, or interviews with process stakeholders;

3. Analyze data gathered in the measurement step. Use statistical analysis to identify actionable changes and predict the effect of improvements
4. Improve product/process. Implement identified changes. Measure the effect of changes. Collect pertinent information via direct observation, simulation, or interviews with process stakeholders. Redefine and refocus objectives to affect further improvement; and
5. Control and maintain the affected changes. Implement statistical process monitoring to prevent process drift. Create a Control Document to clarify procedure for implementing further changes and maintaining quality.

- Identify key aspects of LSS methodology. LSS is a data driven methodology to reducing waste and improving the quality of process outputs. Six Sigma techniques, specifically DMAIC, provide structure for implementing process improvements, and Lean identifies those areas that the DMAIC process can be applied to. Together they provide a comprehensive package of tools for process improvement.
- Execute a LSS-style improvement project in an Inpatient Pharmacy. An area was *Defined* for improvement by identifying key processes within the pharmacy. The scale of the opportunity was *Measured* through observation and baseline data collection. The data was *Analyzed* and presented opportunity for *Improvement*, which the pharmacy acted upon. This document and the template ultimately serve to guide and *Control* the methods for future process improvement projects within the pharmacy.

The most tangible benefits to the hospital involved in the study were the identification of possible improvement projects in the Project Hopper (Table 1), and the execution of the project itself. The hospital will likely see a 15% total reduction in wasted movement, 35% reduction in wasted motion stemming from the U1 role, and now has identified several other opportunities for process improvement. Obviously other hospitals will have different needs and administrative goals, but identifying concerns through a Gemba walk, and following the DMAIC process will bring measurable benefits.

This case study exists, with relation to other similar studies in healthcare related LSS, to highlight the benefits that are possible through application of LSS methodology and to provide the knowledge base and a template for the execution of basic process improvements. Significant opportunities exist in the healthcare industry for cost saving improvements which should ultimately improve the quality of care that patients receive at the hands of healthcare professionals. Some of those opportunities have been identified in the course of this study (Table 1), and many others have been identified in the research which was cited supporting this work. However, any change requires the willpower and initiative to act. Equally important is the support of process stakeholders to accomplishing any substantive changes and maintain control of the process into the future.

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