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Use of Lean Healthcare and DMAIC to Reduce Waste in a Public Hospital

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Abstract: With an increasing demand for quality of care and lower costs, hospitals are looking for industry-based methods to improve efficiency in their processes. This study aims to reduce waste in a public hospital in Mexico by improving the medical supply process for the operating room. To this end, a lean healthcare (LH) implementation following the DMAIC approach (Define-Measure-Analyze-Improve-Control) is carried out. We analyze the value stream of the supply process, including main surgical procedures and their related medical supplies, and identify different causes of inefficiency, which are evaluated and controlled through different tools, including a value stream map, Kanban, and the 5S program. As a result, five types of waste were reduced. Over-processing requests were reduced by 15.3%, defective identification numbers were reduced by 46.5%, redundant processing was improved by 94.8%, near 2.8% of the unnecessary inventory was reduced, and transportation waste was reduced by up to 16.7%. Finally, the lead-time for the main supplies was reduced by 33 days. This work demonstrates that LH and DMAIC are effective in reducing waste and are highly conducive to improving sustainability in healthcare processes. Moreover, it provides practical insights for practitioners regarding the implementation of LH in public hospitals in developing countries.

Keywords: Lean Healthcare; DMAIC; Waste Reduction; Efficiency; Sustainability

1. Introduction

Healthcare organizations face continuous pressure to increase efficiency and reduce waste [1]. Efficiency has become a main goal due to its impacts on safety, quality, and costs. To increase efficiency, hospitals around the world have implemented LH in their processes, with a focus on eliminating waste while increasing the value of a business process [2]. Values are “activities that enhance the quality of healthcare and promote patient well-being so as to achieve better outcomes” [3]. Conversely, wastes are aspects of the service that do not add value to customers [2] and are commonly grouped into seven types which LH aims to reduce: transportation, inventory, motion, waiting, overproduction, over-processing, and defects (Beck, Okerblom, Kumar, Bandyopadhyay, & Scalzi, 2016; Westwood, James-Moore, & Cooke, 2007); though underutilized skills has been proposed as an eighth waste [6]–[8].

The term “lean” originates from the Toyota Production System (TPS), a popular system due to the efficiency demonstrated in Japanese manufacturing companies [9]. Lean, as a system, reached the medical domain in the early 2000s and is commonly known as lean healthcare [10],[11]. Increasing the efficiency of hospital-based clinical care by applying TPS (lean) has been identified as a potent strategy to lower costs and improve outcomes [12]. Thus, different successful case studies of LH have been reported, including establishing streams for patient flows in an emergency department (ED) [13], improving throughput in an ED [14] and cardiac catheterization [15],

improving patient flow in Gynecologic Oncology clinics [16], reducing the wasted time associated with drug dispensing [17], reducing ED length of stay [18], minimizing blood test and waiting times [19], and reduction of patient transportation and waiting times [20],[21], among others.

Another strategy which has been used to increase efficiency is six sigma (SS), which was created to improve product quality by identifying errors and mistakes in manufacturing and business processes [22]. In order to solve problems and reduce variation, SS follows a well-established method known as DMAIC. Studies which have applied SS to healthcare include the reduction of variability in scheduling pre-anesthesia consultations [23], and reduction of appointment lead-time in obstetrics outpatient department [24], among others. The synergy of both LH and SS methodologies, known as LSS, seems to be one of the most innovative and effective approaches in "Operational Excellence"[25], forming an effective quality improvement method which has been widely adopted in the manufacturing industry and also implemented in many health care settings [26]. In the field of health care, LSS has been used to address numerous health care problems [27], in such areas as trauma centers [28], cardiology [29], surgery [30], operating rooms [31], intensive care units (ICUs) [32], rehabilitation wards [23], and otolaryngology care [33].

Accordingly, general lean and six sigma principles have been interpreted and adapted for each organization's unique local context. Despite LSS being excellent for driving process change, it has limitations in the complex social environment of hospitals [30].

1.1 Lean Healthcare and the economic, environmental and social perspective.

Healthcare professionals and managers in many countries have experimented with lean tools and techniques to improve efficiency, clinical outcomes, satisfaction, and safety for both staff and patients, and ultimately, to enhance financial performance and sustainability [25]. In this regard, sustainability researchers have held multiple perspectives ranging from sustaining results over time [25] to concerning the capability for meeting those needs both in the present and future (efficacy, effectiveness, and ethics) [34]. In this research, we adopt the latter perspective.

To achieve sustainable development in an organization, it is crucial to harmonize three core elements: economic growth, social inclusion, and environmental protection [35]. In the economical component, LH helps to reduce costs through a reduction of waste. Worldwide, there have been many LH implementations impacting on operational indicators, including the increase of service capacity [[36]; [23]]; productivity increase [[37]; [38]]; reduction in cost per case/service [[30]; [39]]; reduction of inventory/space [[38]; [14]; [40]]; reduction in transit/transportation time [[41]; [14]]; and reduction in process cycle time [[29]; [17]; [42]; [13]], among others.

In the environmental component, lean produces an operational and cultural environment which is highly conducive to waste minimization and pollution prevention. In fact, in reducing waste, lean has a positive contribution to the improvement of environmental performance [43]. Furthermore, health units have been taking steps to improve energy consumption, renew the way they work, and design more environmentally friendly facilities [44]. In addition, some tangible results of the implementation of lean approaches in hospitals include reductions in energy consumption [45].

In the social component, LH has been positively related to social outcomes e.g., organizational effectiveness, service quality, and customer/patient satisfaction among other sociocultural aspects [46]. To increase patient satisfaction, LH has demonstrated its potential through reduction of patient transportation and waiting times [20],[21].

Despite the inherent relationship between LH and sustainability, Hallam and Contreras (2018) found that only 13.5% of the LH literature included sustainability as a part of their studies [47]. In the global context, lean initiatives first appeared in U.K. health services, followed by the USA [48]; indeed, LH has been predominantly implemented in developed countries [49], [50]. In fact, a literature review showed a scarcity in studies from developing countries [51]. Moreover, there has been little evidence of the implementation of LH in public hospitals; accordingly, there is a need to analyze how LH can be implemented in a particular situation as a basis for explaining the success (or

otherwise) of such an improvement strategy. Therefore, in this study, a LH implementation is conducted to address deficiencies within the medical supply chain of a public hospital in Mexico.

2. Materials and Methods

A lean healthcare implementation following the DMAIC approach, (i.e., the five-phase improvement cycle), was conducted from February 2017 to December 2018 in a public hospital in Mexico. We decided to conduct an explanatory single case study, as it is particularly useful when a subject requires comprehensive investigation from multiple perspectives [52]. The hospital attended to 9,162 patients during 2018, had 127 permanent care beds and 104 temporary care beds, and was staffed by 444 nurses and 120 doctors working in the 42 different services offered by the hospital. The hospital presented a wide variety of opportunities in areas regarding the efficiencies of different processes, as well as in the use of infrastructure and supplies. In this project, we carried out an analysis of inefficiencies in the medical supply process, which represented high volume and costs for the hospital. In conjunction with hospital authorities, we decided to follow the DMAIC approach as it offers great usefulness for the improvement of pre-existing processes and has been implemented in similar cases [22],[26].

Following the proposed methodology, in the “define” phase we reviewed historical data, conducted staff meetings, and interviewed with heads of departments. In addition, we evaluated the value stream of the main processes and conducted exploratory walks through the hospital, which allowed us to generate an initial diagnostic. In this regard, the needs of the hospital authorities were identified, as well as those of the internal customers (in the 42 different hospital services). We defined an opportunity area in the internal medical supply chain, which began in a general warehouse of the medical unit, providing supplies to a temporary warehouse (TW) near the facilities where they are used. This TW provides supplies every day to the 42 services of the hospital. In particular, we focused on the operating room (OR) supply chain, this service being most critical area, according to hospital authorities and because it represented the largest volume of supplies.

In the “measure” stage, in order to identify key variables, a survey and brainstorming meeting with staff was conducted; in addition, a cause-effect diagram was created to identify the possible causes of inefficiency (Figure 1). Subsequently, the routes to the different hospital areas that received supplies from the TW were described and quantified in a spaghetti diagram; then, the areas representing greater movement and transport were identified (Figure 2). Furthermore, volume, type of supplies, and the main services where the supplies were delivered were determined using Pareto analysis (Figure 3). In this sense, the demand for supplies from all services for the years 2017 and 2018 were gathered and examined to understand their patterns of variation. In addition, we elaborated a SIPOC diagram with representative processes and supplies, which were grouped by product families.

In the “analyze” stage, the main surgeries conducted in the OR were analyzed to determine frequency, volume, and type of supplies required in the OR which would satisfy the requirements of these surgical procedures. Then, we developed a surgical demand analysis and forecast using historical data of the years 2016-2018; for this, different time-series methods were evaluated, including moving average, single and double exponential smoothing, and Holt-Winters, as suggested by [53]. Afterward, in order to attain a better understanding of the supply process, a value stream map was generated for the most used family of supplies of the OR (Figure S1). Therefore, we identified activities that generate value and those who don't, in an effort to reduce waste.

In the “improvement” stage, with the commitment and participation of the TW staff, we implemented the 5S program to reorganize the workplace, enhance the cleaning process, and to improve access and space in the TW, which allowed better control of supplies. Moreover, by analyzing the supply demand in the OR along with the most representative families of supplies, an initial inventory management program was developed, as well as the oversight of supply deliveries from the TW. The need to generate supply batches and calculate the average demand was identified, from which a future VSM was developed in order to improve the process (Figure S2). In addition, a Kanban system was developed for supply and stock management (Table S1).

Finally, in the “control” stage, different procedures and instructions were developed and control activities were implemented, including 5S audits, which consisted of formats for the verification of the execution of the improvement activities, reviewing whether they had been implemented, and whether any changes were proposed and if they were approved by senior management, in such a way that a value could be assigned to each activity, such they could be monitored and improvement could be guaranteed.

3. Results

LH intervention in the medical supply chain was conducted. Initially, after a brainstorming session we identified several possible causes regarding deficiencies in the medical supply chain, which were organized using the cause-effect diagram shown in Figure 1.

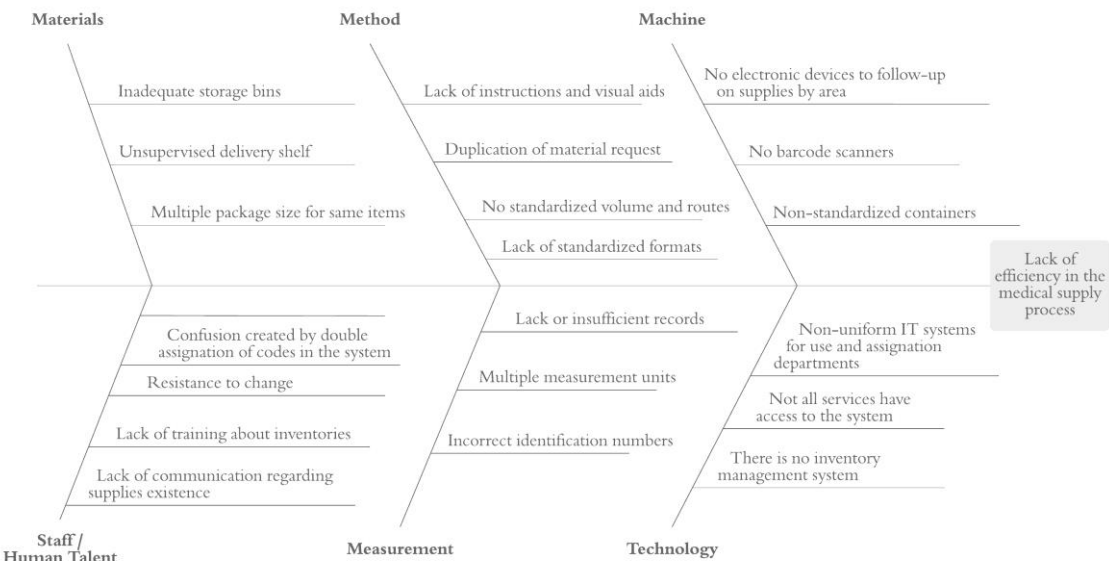
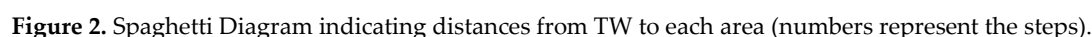


Figure 1. Cause-effect diagram of the lack of efficiency in the medical supply process

Regarding the supply variation, we identified that, from the 42 different areas, all of them requested more material per day at a higher frequency than needed. From the supply analysis, we identified that the OR, as an independent service, was the one which made the highest amount of requisitions from the TW, as shown by the Pareto graph (Figure 3). Therefore, the main surgical procedures and their related medical supplies were analyzed for the years 2016, 2017, and 2018. From the 464 different surgical procedures registered, it was found that the most representative were Caesarean sections (C-section) with 3.7 daily procedures on average, followed by tubal ligations and appendectomies. The demand analysis for C-section obtained better results with the Holt-Winter model ($\alpha = 0.5$, $\beta = 0.05$, MAPE = 0.119, MAD = 27.8), which allowed us to develop a Kanban system to provide the correct amount of supplies on a daily basis to the OR, from which an extract is shown in Table S1.



In connection with the value stream map for the main supplies from TW to OR, we identified that up to 60% of requisitions made to the TW were not correctly provided, in terms of quantities and types of supplies, generating multiple request orders. This type of over-processing waste was reduced by 15.3%. Furthermore, the future value stream map indicated a 33-day reduction in the lead-time, from 45.3 days to 11.9 days for three families of needles, which represented the highest volume of supplies. Additionally, several inconsistencies were found in terms of identification, location, and inventory volume. In this sense, with the commitment and participation of the staff from the different shifts of the TW, implementation of the 5S program allowed organization of the workspace and better control of supplies (Figures S3 and S4).

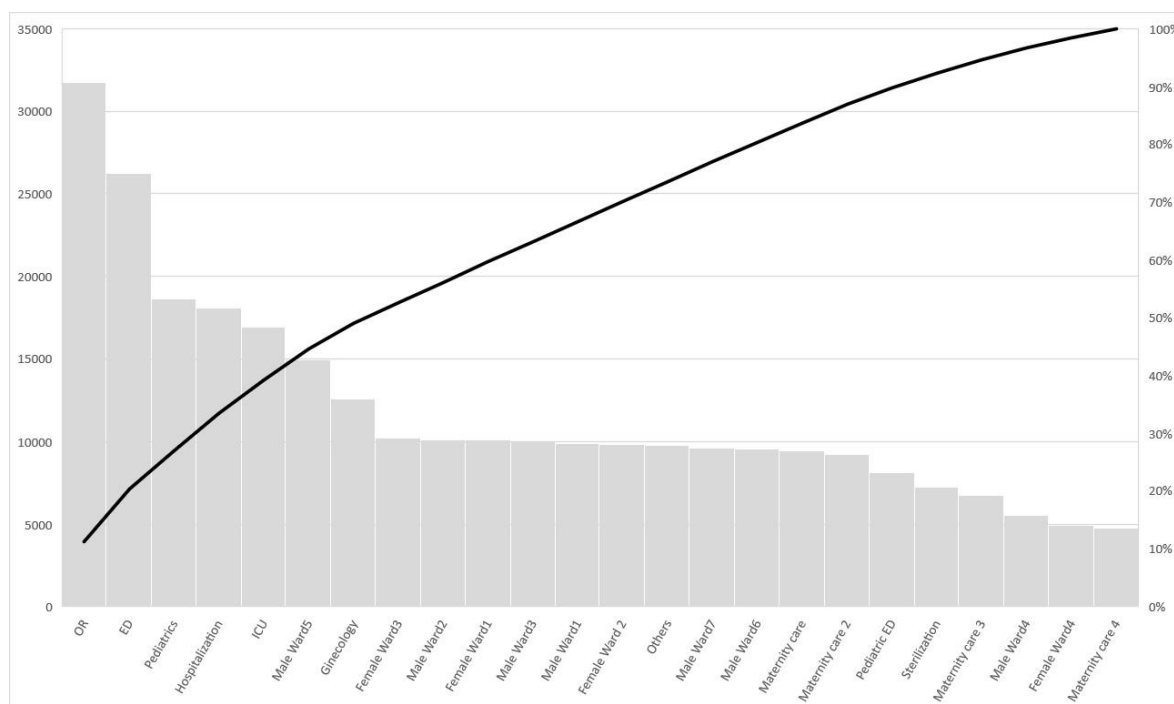


Figure 3. Pareto graph with frequencies of supplies requests by areas during 2017 and 2018.

Moreover, analysis of the codes and identification numbers of all the supplies in the TW system showed 8,256 different items. However, after removal of duplicates or non-existent items, only 4,413 were identified as real items; thus leading to a reduction of defective identification numbers by 46.5%, which might consequently reduce other types of waste. One of the largest reductions of waste was obtained through the elimination of redundant processing and reduction of re-entry of material orders by different areas, which was improved (by 94.8%) from 7,523 to only 388. In addition, we were able to identify and eliminate unnecessary inventories among services, which represented nearly 2.8% of the TW inventory.

4. Discussion

Based on the results, five different types of waste were reduced in a public hospital through a LH implementation following the DMAIC approach. Even though waste was not completely eliminated, an important step was carried out, considering the resource limitations of a public hospital. The reduction of inventory and transportation from the TW to the OR allowed for better control of the warehouse, medical supplies, and the time of the staff. Furthermore, by reducing processing, over-processing, and defective identification numbers, the supply process performance was improved. These findings were similar to [54], regarding LH as having an impact on the supply performance through the medical supply chain. Other benefits of LH include the improvement of the quality related to patient care, safety, elimination of delays, and reduction of length of stay [4]. Moreover, this research supports the findings cited earlier by McCulloch et al. (2010), who found extensive evidence of the benefits of lean in improving efficiency in medical settings [55].

Different efforts to improve efficiency in OR have been made, including: reduction of length of stay [30], reduction of number of door movements [56], reduction of unnecessary instruments delivered to the OR [57], and decrease of turn-over time (TOT) [58], among others. This study complements the literature and provides a different perspective: that of a public hospital located in a developing country, which may provide insight to researchers and practitioners. In addition, we gained knowledge of the processes and obtained a better understanding of the compatibility and

impact of LH and SS initiatives on sustainability, which may be extended to more healthcare processes.

Although this research was conducted mainly on the supply process to the OR, LH and SS are capable of a wide dispersion to other areas, such as surgical waiting lists, emergencies, laboratories, time of occupation of operating rooms, recruitment of personnel, errors in medication, and management of maintenance work orders [56], [59], [60]. Thus, the flexibility of LH and SS are suggested for implementation in different areas of a hospital.

4.1 Waste reduction and sustainability

The definition of waste in lean includes both tangible and intangible factors, such as inefficient machinery and non-value-added movement, respectively; whereas sustainability refers to more tangible issues, such as resource consumption, emission levels, and physical material dumped into landfills [61]. Moreover, lean and six sigma aim to reduce waste and variation, offering a better culture to deploy sustainability. On the other hand, sustainability aims to minimize the negative impacts of processes and activities on the environment, society, and assets [61]; thereby, there exists clear similarity among lean, six sigma and sustainability: waste reduction [61]–[63].

These efforts seem to be a war on waste; however, this is justified by the need to reduce costs that are not essential for the care of patients [64]. Despite the major threats to health services, sustainability which has most often been identified in a financial context, healthcare, (as with all human activity) takes place within social and environmental contexts, not just an economic one [65]. Therefore, the war on waste now has more justification, as well as a need for greener healthcare [64] and social impact. From the broad perspective of lean, most of the literature has concentrated on either cost minimization or profit maximization, or on reducing environmental emissions. Only a few studies have examined the effects of lean on sustainability from the economic standpoint [34].

In addition, LH has been positively related to social outcomes (e.g., organizational effectiveness), in terms of service quality, and customer/patient satisfaction, among other sociocultural aspects [46]. Accordingly, several benefits have been reported by practitioners related to those perceived by the patients such as reduction in the length of stay [[66]; [67]; [30]], wait time reduction [[13]; [68]; [69]], increases in patient safety [[56]; [57]], reduction in time response/lead time [[38]; [68] and, ultimately, all these types of benefits have an impact on patient satisfaction [66]; [38]. However, doctors, nurses, employees, and staff have also perceived benefits from the implementation of LH, including increases of employee satisfaction and motivation [68]; [70]; and empowerment [40]; [4].

On the environmental side, lean produces an organizational culture which is highly conducive to waste minimization, pollution prevention, environmental management systems, and sustainability [71]. In fact, in reducing waste, lean has a positive contribution to the improvement of environmental performance [43]. Thus, health units have been taking steps towards improving energy consumption [45], reducing waste, renewing the way they work, and designing more environmentally friendly facilities [44].

An important aspect while implementing LH in a public hospital relates to the type of management and bureaucracy, which is common throughout the public sector. Therefore, we agree with Radnor and Osborne (2013) regarding the challenges that public services face when implementing lean, such as the impacts of the culture and structures of the public sector and, particularly, the competing professional and managerial roles, as well as a lack of understanding of the centrality of the customer (or service user) and of service processes [48]. Other opportunities include the extension of the 5S to 6S to obtain an additional layer to ensure occupational safety and health levels [72]. In this regard, lean practices and projects may facilitate a focus on sustainability [73], including approaches to integrating lean into different management systems, such as quality, environment, occupational health-safety, and social responsibility systems [74].

In a global context, the United Nations (UN) stated its 2030 Agenda for Sustainable Development and the associated Sustainable Development Goals (SDGs)[75]. Globally, there have been several efforts to contribute to sustainability. The National Health Service (NHS) of England

developed its Sustainable Development Management Plan 2018-2020, which was aligned to the SDGs [76]. In the U.S., the Environmental Protection Agency created a foundational framework for environmental sustainability using lean tools, in order to improve both business performance and environmental performance by identifying and eliminating environmental wastes in organizations [77]. However, there still exist opportunity areas to cover, mainly in developing countries. The critical factors and main tools of LH have room for improvement [78]. In addition, more research focused on LH, SS, and sustainability is needed; mainly because sustainability remains an underestimated theme in the LH literature [25].

Finally, this study had several limitations. First, it was conducted in the specific context of a Mexican public hospital; therefore, contextual factors, such as the healthcare system, training, and culture, may have influenced the results. This limits the external validity and generalizability for public hospitals. Second, because the implementation occurred in one hospital, a larger number of hospitals and/or further longitudinal studies are needed to deepen understanding of embedding LH to improve efficiency in the supply process. Third, the time periods that were compared, may have had different volumes of surgical demand; therefore, comparing similar periods would better address this issue. Obtained savings and financial information were not allowed to be provided, due to a confidentiality agreement. Finally, we did not directly assess the impact of waste reduction on patient satisfaction and staff satisfaction, which are very important outcomes of LH.

5. Conclusions

This study shows that the implementation of LH following the DMAIC method provides an effective approach to reduce waste. In particular, five different wastes were reduced, thereby improving process efficiency. These results have a direct effect on cost reduction, better resource utilization, and reduction of staff processing time, which can lead to a better work climate. Using DMAIC with well-defined steps helped to delimitate the problem and guide towards a solution while implementing lean healthcare; therefore, the combination of lean and six sigma appears to be an effective approach to implement in healthcare processes in order to identify, evaluate, and reduce wastes, as well as increasing efficiency and, therefore, contributing to sustainability. Additionally, results from this study could be extended to other similar processes in hospitals in Latin America, as their idiosyncrasies and ideologies may be similar to those of Mexico. However, it is important to confirm this assumption.

Future research might include the impact of governmental strategies in healthcare to increase efficiency in developing countries, and the cultural and socio-technical factors affecting the implementation of LH and SS within public hospitals, as well as how it can improve supply chain management within public healthcare providers.

Supplementary Materials: The following are available online, Figure S1: actual value stream map, Figure S2: future value stream map, Figure S3: before 5'S program, Figure S4: after 5'S program, Table S1: kanban table.

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