Chapter N

**SUPPLY CHAIN 4.0: LEAN SIX SIGMA, INDUSTRY 4.0 TECHNOLOGIES AND CIRCULAR SUPPLY CHAIN APPLIED TO AN ITALIAN HOSPITAL CASE STUDY**

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**Abstract.** The aim of the paper is presenting a circular supply chain 4.0 in the sector of healthcare of an Italian hospital through the implementation of Lean and Six Sigma techniques to reduce waiting times and improve processes in the surgical unit. Lean Six Sigma methodology is preliminary to a good implementation of Industry 4.0. Before digitalizing and robotizing it is necessary to improve efficiency both in terms of Lean waste and in terms of variance and efficiency for Six Sigma in order to be able to "feed" Industry 4.0 with a product that is already optimized and ready for digitalization. Methodology adopted is based upon a literature review and on a case study. Results show a dramatic increase in the average of the number of surgery interventions and that the jointly adoption of Industry 4.0 technologies, Circular Economy strategies and Lean Six Sigma methodologies enables circular supply chain.

**Keywords.** Lean Six Sigma, Supply Chain 4.0, Digitalized Supply Chain, Circular Supply Chain, Industry 4.0, Healthcare.

1. **Introduction**

There are many similarities between the healthcare sector and the industrial sector, and consequently the healthcare world could also benefit from that broad and consolidated disciplinary corpus that we could call operations management, and which has determined and made possible the exceptional and simultaneous development of the efficiency and effectiveness of the industrial sector in recent decades.

A potential performance improvement could and should be exploited in favor of our health system, also to guarantee greater safety in case of new situations, albeit exceptional, such as that due to Covid-19.

To qualify the main and unavoidable difference between healthcare and industry, it is necessary to underline that in all business to consumer sectors, the most important aspect is not only to prevent diseases or to treat them, when they occur, but also to do so by generating a satisfying customer experience.

Even in the healthcare sector, as in the industrial sector, the quality of the service provided to patients depends on a large jumble of decisions that are intertwined with each other and that we can group, in very aggregate terms, according to the object of the decision, in the *configuration choices* and *system management choices*.

By *configuration choices* we mean all those choices that determine how the hardware (physical structure) and software (organizational structure) of the system are made. Since the modification of the physical or organizational structure of a complex organization such as that operating in healthcare sector requires high investments and equally long timescales, configuration decisions are typically medium-long term decisions, delegated to strategic and setting choices.

*Management choices*, on the other hand, are medium-short term decisions typically made with a given configuration.

Therefore, what we have defined *configuration choices* belong to the *strategic or business level*.

*Management choices* typically belong to the operation and process level.

The dawn of Industry 4.0 technologies, environmental issues such as the need of reducing energy consumption and the spread of health emergencies such as the pandemic Covid-19 have greatly modified the business environment and the business approach of an enterprise.

On the other hand, it has to be highlighted the importance of the implementation of Lean Six Sigma methodology before the introduction of Industry 4.0 technologies in a company.

Therefore, the objective of this paper is to demonstrate the power of Lean Six Sigma with the help of Industry 4.0 emerging technologies in an Italian hospital through the presentation of a case study. The paper is organized as follows: section 2 reviews Lean Six Sigma, Industry 4.0 and Circular supply chain in general. Then, the section turns to Lean Six Sigma and Circular Supply chain in healthcare specifically, to understand their scope of application in this research area. Section 3 concerns methodologies applied; section 4 presents a case study of an Italian hospital; section 5 introduces results and discussion and section 6 conclusions and future perspectives.

1. **Literature background: Lean Six Sigma, Industry 4.0 and Circular Supply chain**

Optimization of processes is a transversal choice that can be carried out both implementing different methodologies such as Lean techniques, Six Sigma or Lean Six Sigma and introducing Industry 4.0 technologies.

Lean tools are focused on defining value and eliminating wastes whereas according to Harry et al., (2000) Six Sigma is “a business process that allows companies to drastically improve their bottom line by designing and monitoring everyday business activities in ways that minimize waste and resources while increasing customer satisfaction”. Hence, Six Sigma aims at eliminating variability and achieving high level of quality.

On the other hand, *Lean Six Sigma* is a methodology of business improvement that is focused on the maximization of shareholder value by improving quality, speed, customer satisfaction and costs. These benefits are achieved by joining tools and principles from both Lean and Six Sigma (George, 2003). Processes improvement, customer satisfaction, and better financial results are achieved through the implementation of Lean Six Sigma by eliminating waste and variation adopting the DMAIC approach (Cherrafi et al., 2016; Salah et al., 2010).

Antony et al. (2021) suggest a sand cone model of Lean Six Sigma evolution from Lean Six Sigma 1.0 to Lean Six Sigma 4.0. Lean six Sigma 4.0 - more technologically enabled.

Gupta et al. (2020) consider that traditional information systems cannot successfully keep up with the growing number of data that companies are being involved today. This exponential growth of data pushes towards the implementation of new technologies (Tissir et al., 2022). Conversely, Lean Six Sigma is based on data analysis to solve complex problems. Thus, Industry 4.0 technologies like Big Data (BD), Cyber-physical systems (CPS), Internet of Things (IoT)… among others can be treated as an infrastructure of the Lean Six Sigma.

According to Ghobakhloo (2020), Industry 4.0 nowadays is not only referred to the manufacturing industry but, it supports the digital transformation of both the industrial and consumer markets with the onset of smart manufacturing and digitalization of delivery channels. Thus, protagonists of the digital era are not only industries and producers but also end-users such as consumers, patients among others.

Another aspect to take into consideration is the archetypic shift of organizations after implementing Industry 4.0 technologies towards circular economy (Rajput and Singh, 2019). Enterprises are adopting emerging technologies in *circular supply chains* to concentrate on the restorative and regenerative features in order to enable the industrial system to reshape the concept of “end of life” (Heyes et al., 2018; Lopes de Sousa Jabbour et al., 2018; Farooque et al., 2019). Thus, Lean Six Sigma is technologically enabled to meet the needs of the circular economy of an enterprise by boosting the environmental performance at various level of the supply chain.

The Circular Supply Chain Management is a new field of study in the literature that investigates technologies and methods that allow the implementation of “circularity” in industry (Canning, 2006).

**2.2 Lean Six Sigma and Circular Supply chain in the Healthcare sector**

Healthcare sector is increasingly adopting Lean Six Sigma methodology, tipically used in the industrial sector for its continuous improvement of services. Despite Lean and Six Sigma are different methodologies, they operate well together in healthcare sector (Henrique and Godinho Filho, 2018). Lean Six Sigma provides a hands-on framework for continuous improvement in healthcare by monitoring costs, improving quality, and supplying better healthcare services (Sohal at al., 2022).

Govindan and Hasanagic (2018) identified healthcare sector as one of the areas in which circular supply chain management could facilitate production and service management. Circularity implies that the product disposal phase becomes the starting point of a new phase for a brand new product. Therefore, it increases the number of the product end-users.

1. **Material and methods**

This section presents the methodology adopted in the study. It is based on a mixed approach, characterized by a detailed literature review and a case study of an Italian hospital.

Firstly, objectives, research questions, keywords and search databases were determined. Regarding the objective and the research question, the article aims at understanding the scope of the main topics: Lean Six Sigma, Industry 4.0 and Circular Supply Chain and their peculiarities in general. Then, Lean Six Sigma and Circular Supply Chain are reviewed in healthcare specifically, to understand their scope of application in this field.

In terms of databases, Google scholar, Scopus and Elsevier were chosen to implement the research. Peer-reviewed journal articles, books and non-academic research such as international reports available online were considered. Subsequently, the following keywords were used: ‘Lean Six Sigma’, ‘Supply Chain 4.0’, ‘Digitalized Supply Chain’, ‘Circular Supply Chain’, ‘Industry 4.0’ and ‘Healthcare’.

Then, the study draws on process information and primary data from a real anonymized project carried out in an Italian hospital. It is outlined the Lean Six Sigma methodology adopted in the case study.

1. **Case study**

The case study focuses on the optimization of the waiting times and improvement of processes in the surgical unit of an Italian hospital.

The goal of the project is fulfilled through the implementation of the Lean Six Sigma methodology and management of end-to-end activities that take the patient from the hospital ward to the surgical unit and vice versa.

* 1. **Problem statement**

A consistent number of surgical interventions were delayed and planned surgical interventions were postponed.

In this context, customer dissatisfaction, long waiting times, postponement of planned surgical interventions, waste of time and resources were some of the main reasons to intervene.

**4.2 Methodology steps**

*Recognize Phase*

In this initial phase, deployment of Lean Six Sigma methodology among employees was carried out. In this respect, a customised course was held to deploy Lean Six Sigma culture and philosophy to train people and make them aware of the cultural change they were going through.

*Define phase*

A cross-functional project team was created, led by two black belts, with the objective of using the define, measure, analyse, improve, and control (DMAIC) six sigma breakthrough methodology in order to reduce the waiting times and improve process efficiency.

Process mapping activities was started and all the internal processes between the hospital wards were officially defined, the processes that flow internally from the outside to the hospital and the processes that make the reverse path going from the hospital outwards.

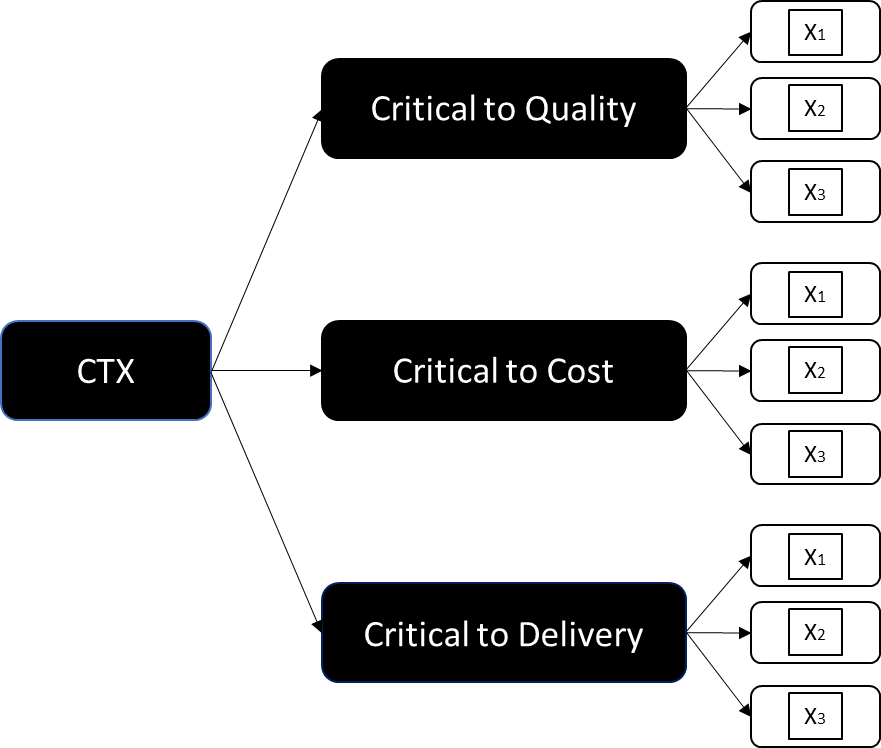
The efficiency was calculated for the first time and it will serve in the future as one of the key indicators to check the quality of the processes.

*Measure Phase*

This activity allowed to identify 8 milestones, essential for planning data collection and development of solutions:

1. medical examination before surgery;
2. patient in the pre-operating room;
3. entrance to the operating room;
4. start induction of anesthesia;
5. patient ready for surgery;
6. surgical incision;
7. suture;
8. exit from the operating room.

Each of these milestones was monitored through the entrance and exit time. In this phase, historical samplings, hospital flows observation, entry forms, metrics calculation, efficiency, total times, Cycle time, Lead times and Takt times are carried out. It is also defined a list of fundamental metrics impacting the times (Critical to Delivery, costs (Critical to Cost) and quality (Critical to Quality) of the services / treatments made available.



**Fig. 1 Fundamental metrics to be identified**

In order to conclude the Measure phase it is essential to have a baseline of the performance of the process, since it is this measure that will allow us to verify whether the improvement actions have actually brought benefits. For this reason, 7 indicators within the Operating Block are identified and their performance is measured. The 7 indicators are classified as in the Table 1.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **ID** |  | **INDICATOR** | **ACRONYM** | **DESCRIPTION** |
| 1. |  | Raw Utilization | RU | Ratio between the sum of the time patients occupy the operating room and the total time available, expressed as a percentage. |
| 2. |  | Start Time Tardiness | STT | Difference between the incision time of the first intervention of the day and the scheduled time of the beginning of the first intervention, expressed in minutes. |
| 3. |  | Over Time | OT | Difference between the last patient's exit time from the operating room and the programmed SLOT end time, expressed in minutes. |
| 4. |  | Under Utilization | UT | Difference between the programmed SLOT end time and the patient's exit time from the operating room, expressed in minutes. |
| 5. |  | Turn Over Time | TOT | Difference between the time of entry into the operating room of the next patient and the time of exit from the operating room of the previous patient, expressed in minutes. |
| 6. |  | Lead Time | LT | Total time spent by the patient in the Operating Block. |
| 7. |  | Patient Operation Efficiency | POE | Number of patients who entered the operating block by surgery/ number of operations performed. |

**Table 1. Indicators identified**

*Analyse Phase*

The analysis phase consists in evaluating how the identified metrics impact on the various processes and if there is a degree of correlation between them. This activity will be preparatory to the improvement phase and will allow to focus on high leverage metrics.

Measurements of the causes of volumes variability, seasonality, percentiles, statistical trends are carried out through simulators, Pareto diagrams, scatter diagrams, Ishikawa diagrams and regression analysis.

*Improve Phase*

The improvement phase aims to find the tools and technologies that allow the three types of metrics, Critical to Quality, Critical to Cost and Critical to Delivery, to reach a higher quality level. In this phase the statistical design of experiments (DOE) is adopted as smart way of analysis.

The objectives of the improvement are based on four fundamental principles:

* Small batches to manage;
* Connected and communicating processes;
* Setting the takt-time;
* General coordination.

The strategic objective to be aimed at is the fluid scheduling of elective surgery.

Three improvement tools which aim to improve the management of all the processes of the Operating Block are developed.

All of them are computer-based tools supported by Cloud Computing, a paradigm that empowers “Utility Computing”, i.e. the leasing of computing resources (computational power, storage, and the related networking resources) in real time, with negligible interaction with the provider.

1. Planning of the operating rooms: the objective of this improvement tool is the early planning of the surgical interventions to optimize the planning and execution of the activities inherent to the processes of the operating block;
2. Plan Matrix: the aim this second tool is monitoring the deviations between the critical phases of the operative flow in order to create a continuous improvement loop within the entire operating block. This tool, based on a live monitor, allows to identify, categorize and eliminate all possible causes of delays, errors and non-conformities that may arise within the operating block;
3. Surgical intervention check list: this third tool is focused on the anticipation of the collection of important information regarding the patient in order to optimize and reduce the stay of the patient within the operating block. *Control Phase*

The control phase, on the other hand, is used to implement monitoring software and tools so that there is constant attention to preserving the quality levels achieved.

1. **Results and discussion**

The main managerial results deriving from the project were in terms of management’s approach to Lean Six Sigma and the need to adopt Industry 4.0 technologies for supporting it.The application of Lean Six Sigma has to be preliminary to Industry 4.0 implementation in a company. Then, the Lean Six Sigma for continuous improvement made senior management aware of the importance of employee involvement in the cultural change an organization is going through. The preparatory training for employees was essential to prepare the staff to a culture of continuous improvement as well as to learn how to design processes and how to interpret metrics.

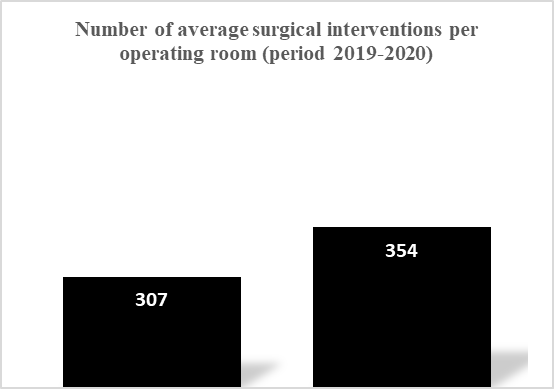
Better utilisation of resources reduced operational costs, reduced waiting times for patients and therefore an improved customer service are crucial factors for the long-term sustainability of a hospital. In this case study it was observed:

• reduction of delays associated with patient preparation activities;

• risk reduction in the surgical process through the implementation of predefined safety standards;

• reduction of non-value added times of anesthetic activities;

• increase in the number of surgical interventions in the period between 2019-2020 (Fig. 2);



**+ 15%**

**Fig. 2 Average surgical interventions**

• finally, the operating block was able to optimize activities and achieved a 13.2% increase in productivity in the number of surgical interventions.

Hence, key lessons to be learned are related to the first phase (recognize) and the last phase (control) of project:

1. In the recognize phase, deployment of Lean Six Sigma culture is acknowledged as an essential part in the improvement process.
2. In the control phase, improvement is documented and the implementation of Lean Six Sigma in a sustainable way with training and with the management of improvement projects from the inside of the organization has led the hospital to grow in a logic of continuous improvement.
3. The implementation of Industry 4.0 technologies such as cloud computing proved the importance of the technological support.

In this respect, plans for further implementation of Lean Six Sigma and information technologies are arranged. A management software that will lead to the automation of metrics control is under consideration.

1. A circular supply chain is implemented focused on zero waste.

However, it may be required for a black belt, after a given time, to re-control the process, to guarantee improvement actions are correctly operating

**6. Conclusions and future perspective**

Hospitals are increasingly struggling to provide high quality services to patients despite they have been facing different issues in the last few years such as the pandemic Covid-19 and the need to become environmentally-friendly.

In the case study, an Italian hospital with the aim of improving its waiting times for surgical interventions is introduced. Through Lean Six Sigma method and new technologies a dramatic improvement in efficiency is achieved. The number of interventions and the overall productivity are increased and a reduction in waiting times is achieved.

The case study illustrated within the paper offers interesting insights on the goodness of Lean Six Sigma in hospitals and the feasibility of creating a Supply Chain 4.0, therefore enabled with the emerging technologies (Chen et al., 2022).

This kind of supply chain in the service sector of hospitals, in the light of the case study, can also become circular, in the sense that it is focused on eliminating wastes. In the specific case we dealt with, wastes are to be intended as long waiting times for surgical interventions, lack or reduction in productivity and, therefore, circularity is given by the standardization of the process’s duration in flows with no wastes and the employees training. Future works have to be focused on the meaning of circularity in hospitals and its interaction with the implementation of Lean Six Sigma.

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