POLITECNICO DI TORINO

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Lean healthcare application for patient flow analysis in Cardiology Department

Candidate

Emanuela Maione

Advisor

Prof.ssa Bruno Giulia

Co-Advisor

Prof Lombardi Franco

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Introduction

“Healthy citizens are the greatest asset any country can have.”

Winston Churchill

Healthcare systems accounts for a significant part of the service sector worldwide. In recent years, hospitals are increasing the use of technological innovations to provide high-quality services. But what are those services? When considering hospitals, clinics and all different facilities belonging to the healthcare system, it is crucial to keep in mind that the final outcomes and goods delivered are health and treatments for patients. Problems in the healthcare system arise when considering its complexity: a multitude of actors interacting each other, a massive number of procedures and operations, several different roles, needs and equipment to consider. As consequence the high number of variables and the unpredictability of their interactions make healthcare system indeterministic, which means that future state and configurations cannot be easily predicted by investigating and extrapolating the past. Moreover, in the last decade, the healthcare system has been dealing with several challenges worldwide. First, healthcare facilities are constantly trying to meet, with limited resources, either in terms of personnel or equipment and space, the increased demand, mostly due to increasing life expectancy and population size and to unhealthy lifestyles; on the other hand, governments are facing rising healthcare costs as the result of the economic crisis. Experts coming from different domains (Operational Research, Industrial and Management Engineering, Data Analytics, Artificial Intelligence, Computer Science, etc.) face a huge challenge in applying their knowledge to improve health-care systems. Therefore, it is necessary to identify new ways to efficiently provide care, satisfying as much as possible customers' expectations (Crema, M. and Verbano, C., 2019).

The thesis is aiming at strengthening the effects of implementation of lean principles when applied in healthcare context. In the first chapter will be presented a big picture of Italian healthcare system, in order to define main features of the industry taken into consideration, especially challenges and criticalities that are constantly pushing innovation and improvement in the healthcare environment.

In the second chapter the key concepts and values of lean thinking will be described, highlighting how lean philosophy modifies company's attitude toward improvements and changes, enhancing optimization of resources and the reduction of all possible source of waste, through the entire values stream. In this context, several lean tools will be presented in order to understand practical application of the principles and the results expected from the adoption of each tool in the different contexts. In the third chapter the general managerial philosophy will be declined in healthcare settings, since this specific sector differs from other industries and business models for several features. It has to be considered that worldwide healthcare is facing a period of reduction of investments and expenditure, while aging population and increase of unhealthy lifestyles is increasing overtime the demand for healthcare services. This set the basis for a perfect matching of lean applications and healthcare sector; some successful examples will be explained to demonstrate the effectiveness of purely production theory in healthcare sector. In the fourth chapter, Simulation Modelling will be presented, since this tool is frequently used to test effectiveness of Lean principles. In this case, simulation modelling allows to provide a simplified computer-based representation of the model considered, avoiding risks and reducing costs of implementation; this aspect is crucial when dealing with funds shortage context as healthcare, since experimentation of different scenarios through a simulation software will not increase risks in the evaluation of impacts of possible changes. Analogies between lean principles and simulation modelling will be underlined, reporting evidences of mutual benefit of joint application. In the fifth chapter will be presented the core of thesis, which is an application, implemented in the Cardiology ward of Maria Vittoria Hospital of Turin. The project aims at optimizing one of the most frequent invasive procedural process performed inside the ward, through the application of lean principles. A complete description of the process will be presented, reporting main criticalities and source of intervention. Finally, the results of the analysis will be discussed, proposing some solutions and implementations of the current state of the Department.

Chapter 1 Healthcare System

1.1 Italian HealthCare System

The Healthcare System is a complex organized institution, composed by individuals, entities, material and human resources, aimed at promoting, ensuring and protecting health of the entire population.

The National Health Service (in Italian *Servizio Sanitario Nazionale SSN*), established by Law n° 833 of 1978, provides health care to all citizens irrespective of gender, residence, age and income, in accordance with some basic principles:

- Public accountability for healthcare protection;
- Universality and fairness of access to health services;
- Overall coverage, as required by the essential levels of care;
- Public financing through general taxation.

In the World Health Report 2000 reported by the World Health Organization (WHO), evaluating five performance indicators in 191 member states, Italy was awarded with second position Italy, preceded only by France. Despite lower than average health spending, Italy has the fourth highest life expectancy across Organisation for Economic Co-operation and Development (OECD) countries, and it is among the lowest countries in terms of rate of preventable mortality.

From an organisational point of view, the governance of the system is exercised by the State and the regions, according to the distribution of competences established by the Constitutional Charter and the relevant legislation. The constitutional provisions provide a complex partitioning of competences in the field of health.

The central level, represented by State and Ministry of Health is responsible for determining the minimum level of medical, civil and social care (known as *"Livelli Essenziali di Assistenza"* or *LEA*) that must be provided to all citizens and foreign residents, according to the *Art.32* of the Italian Constitution; moreover, it is in charge to control and share the budget coming from direct taxation between regional administrations and to introduce common areas of action; the organisation and implementation of health services instead falls within the competences of local level, represented by different regions, which are entitled of achieving country's health objectives. Thus, the regions regulate healthcare system in each specific area in accordance with the fundamental principles, the essential levels and budgets identified by the central level. The regional organisation is then composed by two public entities: *ASL Azienda Sanitaria Locale and ASO Azienda Sanitaria Ospedaliera*. The ASL are autonomous from an organizational, technical, administrative and patrimonial perspective- within the limits of the outlined national framework- and they are financed based on a complex criterion called *quota capitaria*, varying according to regions and depending on the number of citizens resident in each specific area. Instead, ASOs are entitled to ensure specialized medical treatment and are financed on service basis, accordingly to diagnosis-related group classification (namely classes of patients which absorbing homogenous level of resources) associated to each specific treatment provided.

Clearly, from this brief explanation emerges the complexity of public Italian healthcare system: differently from the organization of most of healthcare system worldwide, Italian system is an aggregation of 21 autonomous regional systems, a central Minister and a series of national entities and agencies, therefore the entire system cannot be considered as a unique body.

Another critical point is related to cost, since, similarly to the rest of the world, containing health care expenditure is one of the measures adopted by the Italian government to reduce high public debt. In recent years, the government introduced a series of measures to enact the cost-reduction and promote efficiency; unfortunately, as consequence of the *"regionality"* of the system, those measures have not been implemented in all the regions and even when implemented, not in the same manner. Concerning the expenditure in health, Italy is slightly lower than the average of the OECD countries expenditure. As reported in the *Health at a Glance* report of the OECD, in 2018 Italian expenditure was 3428 US dollars/capita, against the average 3992 US dollars/capita of the OECD countries; particulary, 74% of the expenditure is financed by governament spending (around 2545 US dollars/capita), while the remaining 26% is financed through voluntary or out-of-pocket payments, which means that is directly paid by citizens (OECD, 2019). The latter reports an increase in the percentage of the voluntrary funding and consequently a reduction in the public financing for health expenditure, letting Italy above the average value of EU countries (around 15%). In fact, according to OECD while primary care (i.e. general outpatient care, preventive services, home-based curative services and other different services depending on the country) and inpatient care in hospital are free, specialist visits, medicines and diagnostic procedures are partially or fully paid by citizens. With respect to the Gross Domestic Product (GDP), the healthcare spending in 2018 is again slightly below the average of the EU countries (8.9% in Italy versus 9% in EU), but this value is considerably distant from values of Germany (11.3%) and France (11%).

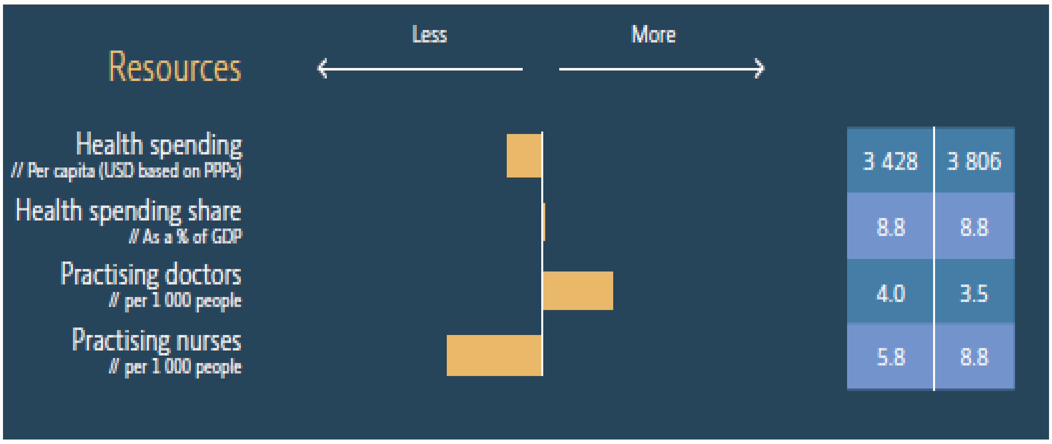


Figure 1 Health Resources compared to OECD Average (Source: OECD (2019), Health at a Glance 2019: OECD Indicators, OECD Publishing, Paris, https://doi.org/10.1787/4dd50c09-en.)

In relation to the workforce in the healthcare system, it is possible to notice a higher ratio of doctor per patients – 3.8 per 1000 population-, with respect to the 3.6 of the EU averages; contrary, the number of nurses for a sample of patients is only 6.1 per 1000 patients, against the 8.4 of the EU averages. This implies that Italy has one of the lowest ratios of nurses per doctor (only 1.5 against 2.3 EU average); nevertheless, nurses are gaining importance in chronic patient care and in the management of primary care. The ***Figure 2*** reports the healthcare expenditure divided by the type of service provided; it can be noticed that Italy is aligned with the average of OECD countries, with an inpatient care moderately higher than the average value.

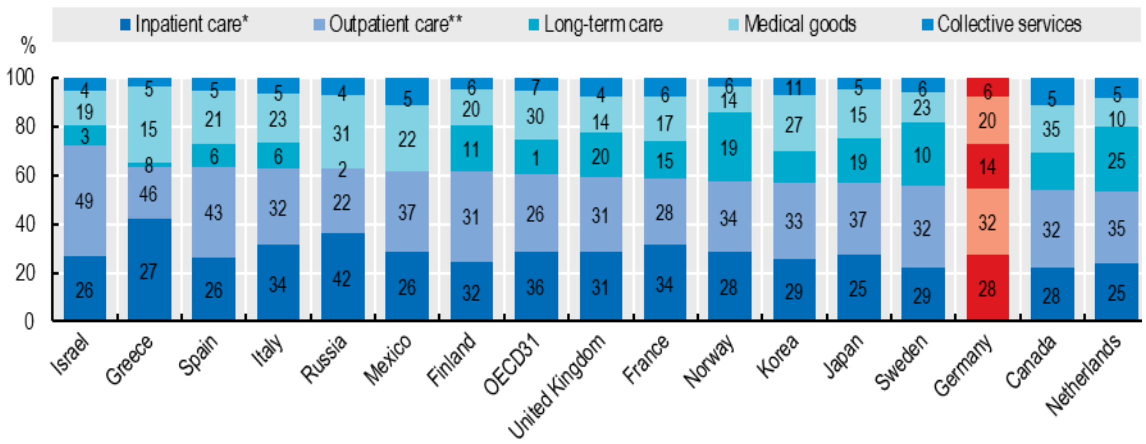


Figure 2 Health expenditure by type of service, 2017 (Source: OECD Health Statistics 2019)

Proceeding in the preliminary analysis of the healthcare system, an important value is number of hospital beds, which indicates the resource available for inpatients; of course the availability of beds has impact also on another important parameter, the admission rates, since generally the higher is the availability of beds, the higher is the admission rate, and in turns the higher is the efficiency of the system, because of the reduction of overcrowding and delays in hospitals. Concerning Italy, as shown in ***Figure 3***, the number of beds per sample of population (1000 patients) in 2017 was 3,2, which is lower than the 4,7 of the average in OECD and it is also lower than the same indicator computed in 2000, reporting as other countries, a decrease in the number of beds. However, regional differences arise, since southern regions reporting a lower capacity. Another indicator of the efficiency of a healthcare system is the average length of stay (i.e. the average number of days patients spend in hospital), which has not reduced since 2000, being stable around 7,8 (***Figure 3****)* and very close to the average of OECD (7,7).

	Hospital beds		Hospital discharge rates		Average LOS	
OECD36	5,8	4,7	158,3	153,9	9,4	7,7
Italy	4,7	3,2	174,2	116,0	7,5	7,8

2000	2017

Figure 3 Average Hospital beds and discharge rates Italy vs OECD average , 2000 and 2017 (Source: OECD Health Statistics 2019.)

In order to improve overall performances and efficiencies of Italian hospitals, the government is promoting stronger efforts to adopt new technologies.

1.1.1 Piedmont Healthcare System

Previously, it has been mentioned the regional division of the Italian healthcare system; for this reason, this work will focus on Piedmont healthcare system.

As reported by the Piedmont region, the system is composed by:

- 12 ASL; 3 ASO; 3 University Hospitals;
- Nearly 54.000 employees;
- € 8 billion expenditure per year;
- € 1,928 per citizen to deliver public health[1].

Table 1 Trend in the rate of hospitalization of 1,000 patients in a group of Italian regions 2013-2017 (Source:Rapporti di Monitoraggio dei Livelli Essenziali di Assistenza – Ministero della Salute – vari anni).

Regione	2013	2017	Variazione % 2017/2013
Piemonte	137,7	122,8	-10,8
Lombardia	134,3	122,3	-8,9
Veneto	126,0	120,0	-4,8

One of the future challenges of the region is the reduction of waiting times, through increasing number of workforce and specific services and extending the opening hours of facilities and clinics. In addition, as decided by a regional provision, in order to reduce the impact of chronic diseases — which are among the main causes of death in Italy— by the end of the first semester of 2019, each ASL must present a new plan for chronic disease, including an increase of home-based treatments and strengthening of health network among different districts.

1.2 Challenges of Healthcare System

Over the years, delivering and financing high-quality healthcare services has becoming one of main global objective: the quality of the healthcare reflects

[1] Referring to 2017. Source: Ministry of Health data elaborated in the OASI Bocconi Report 2018

citizen’s perception of their quality of life (CGI Group Inc., 2014). However, it is important to briefly identify the main challenges of this ecosystem.

Rising costs. There are several underlying factors which would lead to a constant increase in healthcare costs. Firstly, an expected increase in the demand; a large portion of healthcare expenditure is incurred by +65 patients and it is expected to grow, because of increasing aging population, and consequently, the cases of chronic diseases associated with aging. Moreover, increasing lifestyle related diseases (as alcohol, smoke and drugs abuse and obesity) are expected to drive up the demand. Another determinant for rising demand and expenditure is the introduction of new technologies and therapies; in fact, this is likely to boost demands for new treatments, but also to costs – at least in the short run – related to their implementation (Hurst, 2000).

From supply driven towards demand driven. Patients are becoming more than users in their care path: they require to have the highest quality possible of the service at the lowest cost and at highest rapidity. The easiness of access to medical information through Internet is increasing *customers*’ consciousness on their medical needs and requests, reducing information asymmetry, characterizing healthcare environment. Consequently, healthcare organizations should focus deeply on what customers wants (CGI Group Inc., 2014).

Cybersecurity. Due to the increasing role of information systems in healthcare context to collect sensitive data about patients, the sector has become an easy target of cybercrime. From 2008 to 2019, there is a growing trend in data breach occurrences with respect to healthcare providers, with 32 million of patient records breached only in the first half of 2019 [2]. Healthcare organisation should increase their responsiveness against cybercriminals, not only to ensure confidentiality of medical records, but also to prevent injunctions for violation of security standards.

[2] https://medium.com/@MailMyStatement/5-major-challenges-facing-the-healthcare-industry-in-2019-60218336385f

Chapter 2 Lean Management

Lean Management is a managerial philosophy based on the reduction of any *waste* identified within the business, with the purpose of maximizing the value provided to customers; value refers to what is capable of satisfying customers, whereas waste is defined as every activity which does not provide an increased value for the customers. In this sense, Lean management seeks to reduce any waste by identifying each step in the process and then revising or eliminating all the steps that do not create value, from the customers' perspective.

The term Lean management, inspired by the Japanese manufacturing company Toyota, was used for the first time in the early 90's by MIT's researchers Womack, Jones and Ross, in their book "*The Machine That Changed the World: The Story of Lean Production-Toyota's Secret Weapon in the Global Car Wars that is Revolutionizing World Industry*", which described innovation deriving from Toyota's production system and the consequent competitive advantage the company gained with respect to American car manufacturing companies.

From that point on, Lean management has become a reference in the purpose of re-designing management methods with the aim of *obtaining more value using less* (less resources, less human effort, less time, less space and less inventory). (James P. Womack, Daniel T. Jones & Daniel Roos, 1990).

Since the implementation of the underlying principles is not strictly related to manufacturing companies, Lean management has been used by a wide variety of companies worldwide, from logistic, to administrative or design processes. As matter of fact, over the years the general lean production model has been adapted to different settings, under the terms of lean organization, lean manufacturing, lean service, lean office, lean enterprise and lean thinking; the different applications are still fastened to the core principles of lean philosophy, but some aspects slightly change with respect to the different context in which they are applied.

One of the main challenges in the Lean management is the difficulty arising from the fact that no pre-established model or schemes can be automatically adapted to, but the principles must be adjusted to the company-specific context. Furthermore, the adoption of Lean management requires great effort from the top management, who is demanded first to learn in-dept the principles behind the lean method and then to involve staff, guiding and setting the foundations of the transformation. (B.Carminati)

2.1 Lean Thinking

Lean thinking is a managerial mindset focused on the elimination of waste with the goal of creating value; this implies that lean management is not simply cost cutting technique: the elimination of waste is related with value provided, since any process or activity consuming resources and not adding value is considered waste; hence cost cutting is just a consequence of a broader goal.

The concept of Lean thinking has been introduced for the first time by Womack and Jones in their book “Lean Thinking: banish waste and create health in your corporation” (James P. Womack & Daniel T. Jones, 1997). According to their vision, the implementation of Lean thinking is based on five core principles, to be followed within a company.

Identify Value. The starting point in the application of Lean thinking is understand what customer value is; value can be defined exclusively by the customer in terms of final product/service which meets customer’s requirement given a specific price and moment in time. Consumption of resources should be allowed only for increasing the value, otherwise it must be considered as a waste. It is necessary to discover what customer needs, even in case those needs are potential, rather than actual, especially in case of new products development. There are many techniques either qualitative or quantitative such as interviews, surveys and web analytics that can be used to identify what customers want from products. From the customer’s perspective, in fact, only a limited percentage of time and resourced is spent for adding value to products or services (Liker, 2004).

Map Value Stream. Once understood customer’s value, it is necessary to identify and focus on all those activities that contribute to create value. To do so, mapping value stream involves the identification of the path through which value is created. By looking at the big picture, activities which do not add value can be divided in two groups: non-value added but necessary and non- value added and unnecessary; the latter can be immediately eliminated (as for instance, delays, rework or waiting), whereas the former should be reduced or eliminated but not immediately, since they are results of technical, structural or safety constraints. As consequence, once eliminating and reducing those steps, it is possible to reduce cost and to focus alongside on customer needs. The main tool used by Lean to complete this principle is the *Value Stream Mapping (VSM),* defined as visual and graphic representation of all activities needed for each process.

Create Flow. After having identified value and removing unnecessary stages from value stream, the next step is focusing on value-adding activities. The aim is standardisation of processes, so to ensure that the flow runs constantly and continuously, resulting in a lower total processing time and, consequently, a lower lead time for the final customer. In the definition of the flow, it is crucial the concern to the entire production process rather than focusing on single activities within the path. Among actions for assuring a smooth flow it is possible to find re-engineering of production stages, levelling of workload, creating cross-functional departments, and training employees to be adaptive and responsive to changes.

Establish Pull. Contrarily to Push production system, in which production is based on estimated demand, in a Pull-type production system the production is triggered on the actual demand, starting from orders od customers. The adoption of a pull production system is necessary to reduce inventory and stock level, so that resources and information are effectively available for products and not wasted through process. In other words, a pull system allows to deliver to customers the right quantity at right time (Just in Time).

Pursue Perfection. Once identified the value, the flow and how to ensure that all steps run continuously and without delays, the company should focus on pursuing perfection through small but constant improvements. Perfection, ideally, implies reduction of costs, utilisation of all types of resources, including time, elimination of wastes and stock, while ensuring a wide variety of high-quality products or services. The last principle in fact is considered the most important, since it requires the embodiment of Lean concept within the organization, so that the company should always find ways to improve every day.

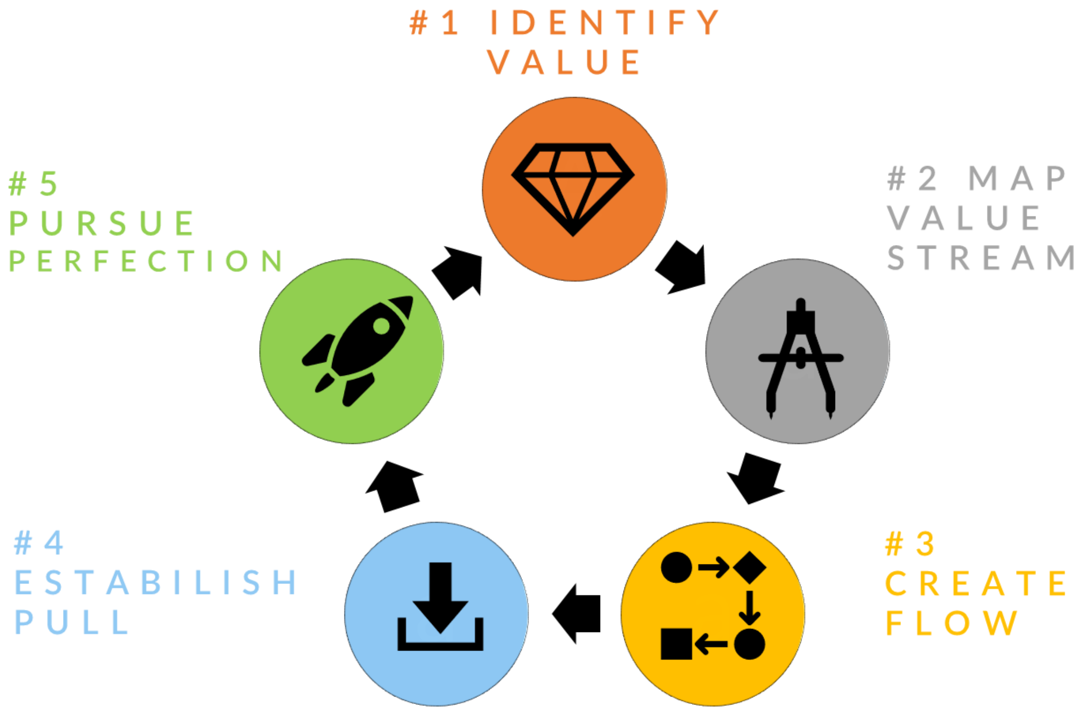


Figure 4 Five Principles of Lean

2.2 A brief history of the Lean

Although the concept of Lean management is strictly related to Toyota Production system, it was continuously revived with the changing times and needs of the industry; hence different actors played a key role in building Lean philosophy. The first application of Lean management dates to organization of the Arsenal in Venice in the 1450s; the Arsenal was used to manufacture ships, especially warships, and all the equipment needed for navigation. In the 1500s, the Arsenal achieved the highest complexity in terms of production and capacity. The layout of the Arsenal was designed in order to facilitate the assembling process: administrative offices were placed at the entrance, all different workstations were efficiently linked, surrounded by specialized area for complementary craftsman steps, armoires and warehouse to store materials. This disposition minimizes unnecessary movements, encouraging the flow, which was organized based on the demand, strictly related to the unexpected attacks of Turkish fleet (Payaro, 2017).

Later, in the Industrial Revolution of the 19th century, machines replaced most of the manufacturing work from men, and factories raised against craftsmen's workshops. One of the main grounds of this epochal change was the introduction of interchangeable parts, in the 1799 by Eli Whitney, which used them to assemble muskets, allowing unskilled workers to produce large numbers of weapons with a significant reduction of time and cost, and, in addition, with an important simplification of the process of replacement of parts.

In the early 1890, observing methods and workers in factories, Frederick Taylor together with Frank and Lillian Gilbreth introduced the concepts of time study and motion study, in order to achieve efficiency in the work methods, processes and operations. The so-called time and motion studies are a significant part of Scientific Management introduced by Taylor. From the perspective of Scientific Management, time study is concerned in establishing standard times, while motion study aimed in developing a technique for improving work methods.

The first person who integrated the concept of lean in the manufacturing system was Henry Ford, with the definition of the flow associated with the process, which some years later inspired Toyota in the definition of its production system. In manufacturing the Model T and focusing on making the product in the best possible way, Ford pursued possible strategies to eliminate waste and to increase efficiency of employees, which can be considered as first integration of lean philosophy. He was especially concerned with reduction of unproductive activities (his factories were designed optimizing steps and movements of workers) and with reduction of unused materials in manufacturing of cars. Furthermore, Ford established the basis of the Fordism, described as «*a model of economic expansion and technological progress based on mass production: the manufacture of standardized products in huge volumes using special purpose machinery and unskilled labor* » (Steven Tolliday & Jonathan Zeitlin, New York).

This philosophy was based on three main pillars: the standardization of the items, which marked the shifting paradigm from craft production to mass production; the use of assembly lines, enabling the reduction of the production costs, in which the process was divided into small and simple tasks performed by unskilled employees with the use of special-purpose tools; and, lastly, the increasing wages for workers, in order to allow workforce to purchase the products they made. The major advantages derived from mass production are a substantial reduction in costs and increase in productivity. The former is mainly due to the reduction of labour cost, with respect to craft production, because of the employment of unskilled workers, the reduction of components and the limited variety of products, because of standardization of items and components; the latter instead is granted by the simplification and reduction of tasks, especially given by the usage of specific-purpose equipment. This set the basis of new way of production system, in which items were produce in large volumes, in an automated way because of the use of assembly lines, which reduced production times and labour costs.

Only in 1930s and strongly after World War II, Toyota revisited Ford's original thinking, and invented the Toyota Production System. Starting from the idea of flow, Toyota paved the way of a new system, focused on the workflow of the entire process, rather than the use and utilization of single machines.

2.3 Toyota Production System

2.3.1 The origins of Toyota Production System

Toyota Motor Corporation was born as a division of the Toyoda Automatic Loom in 1933 by Kiichiro Toyoda, through funding's derived from sale of patent for an electric weaving loom, invented previously by Kiichiro's father, Sakichi Toyoda (Liker, 2004) (Ōhno, 1988). The idea behind this invention became a foundation for *Jidoka* (automatization), one of the main pillars on which Toyota Production System was built.

From 1925 until the World War II, Ford, General Motors and other American carmakers had factories in Japan, dominating the market. It took a couple of years for Toyota to produce its first vehicles, and in the 1935 they launched the A1 passenger car and the G1 truck; only in 1937 Toyota Motor Company became an independent motor company.

In those years, Japanese automotive market suffered a drop in the demand, because of several conflicts and turmoil tearing the country; therefore, it was necessary to decrease the number of cars to be produced and assembled. Kiichiro Toyoda thought that by changing the production system was the only possible way to face the established mass production system. In fact, he understood that implementing a flexible production process, customers would obtain high quality vehicles, with reasonable prices and enough variety (Liker, 2004) (Ohno, The Toyota Production System: Beyond Large-Scale Production, 1988). Kiichiro started to organize the process, enabling the system to produce Just-in-time, setting the basis of a *pull* production system, derived from market needs.

In 1950 Toyotas Chief Executive Officer (CEO) Eiji Toyoda – a cousin of Kiichiro Toyoda – visited Ford River Rouge Complex at Dearborn, Michigan, to examine and collect information that could improve their production system. By analysing the market leaders, they observed a huge waste of resources: differences in operations of Ford and GM and interruptions in the process forced creation of several buffers where intermediate products were stored; moreover, because of the over productions, defects on the intermediate products were not identified (Ohno, The Toyota Production System: Beyond Large-Scale Production, 1988) (Liker, 2004). Based on this experience, Toyota's engineers started to re-design the production process, leading to the Toyota Production System House, which will be discussed in detail in the following paragraph.

The Toyota Production System did not arouse interest in Japanese and American companies until the 1973, when the oil crisis and the consequent global recession brought out the higher profitability of Toyota Motor Company with respect to other companies. This led managers and market expert wondering what was differentiating Toyota from other companies (Ohno, Workplace Management, 2007).

Later, in the 1980s, it became clear that Toyota was delivering to customers higher quality products, designed in shorter times and with competitive prices, keeping at the same time employees motivated by ensuring a good working environment and avoiding alienation because of excessive repetitiveness of work.

2.3.2 Toyota Production System House

The Toyota Production System House –in short TPS House– is graphical representation of all the element composing the Toyota Production System, depicted in form of a house. The house, in fact, represents a structural system: the house is strong only if all the elements composing it are strong; each element of the house is essential, but what is crucial is the way in which different elements have linked each other. The house is structured in three main parts: the foundations on the bottom; the pillars, representing the core activities, in the middle; the goals in the roof of the house. In order to fully understand how the system works, it is necessary to start from the top of the house.

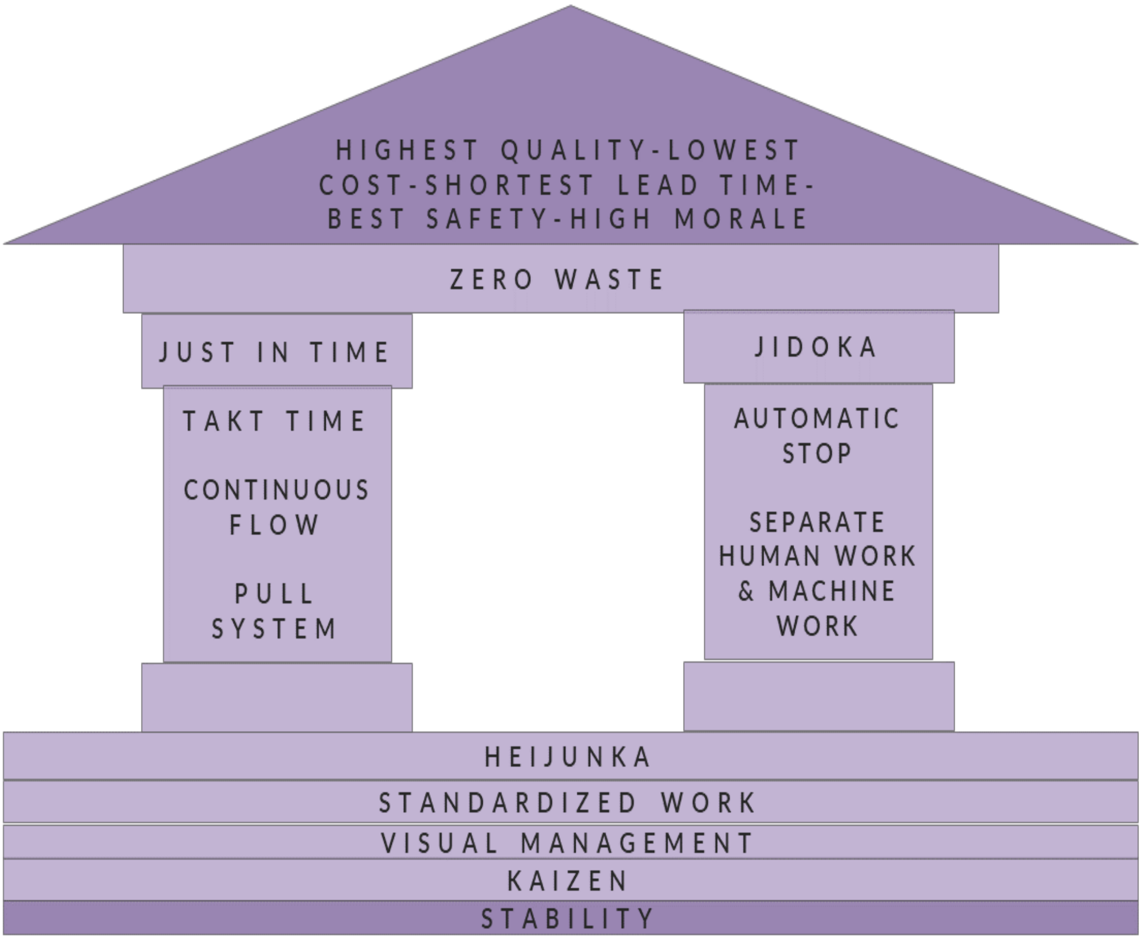


Figure 5 Toyota Production System House

2.3.2.1 TPS Goals

As reported in the ***Figure 5,*** the main goals of the TPS are best quality, lowest cost, and shortest lead time, together with best safety and high moral, aimed at achieving greater satisfaction for all participants involved: customers, employees and investors. The driving force of the TPS to reach these goals is the elimination of waste. Waste, usually named with Japanese term *Muda (無駄)*, consists of all those activities or ways of using resources that do not add value to the product. Therefore, anything that does not increase the value of the product from the customer's perspective and for which the customer is willing to pay, is considered waste and, in theory, should be eliminated.

There are seven main types of waste: waste of overproduction, waste of waiting, waste of transportation, waste of processing, waste of inventory, waste of motion and waste of defects (Liker, 2004) (Ohno, The Toyota Production System: Beyond Large-Scale Production, 1988).

*Overproduction. O*verproduction can be of two types: producing too much or producing before it is actually needed. Overproduction is considered the worst type of waste, since it is the origin of other types of waste, in particular inventory, because of the huge number of items to be stored, defects, since increasing the production volumes reduces the possibility to identify defects and transportation. Overproduction is generally caused by under-utilisation of a high capacity equipment or the use of poor estimation tools for production.

Waiting. It is the easiest waste to identify. Generally, when a product is not being processed or transported, there is a waiting time, which implies waste of resources and money. Waiting is caused by unsynchronized and unbalanced processes: if the first activity takes longer than the following must wait until the previous is finished, in turns delaying the whole production process. Other causes may be unscheduled breakdowns, unavailability of raw materials or poor layout or work sequences.

Transportation. During the production process materials, components and products need to be transported within the plant. Ideally all not necessary transfers or actions should be eliminated from the work process, but in practice inefficient layout and facility designs lead to long and inefficient transportation paths, for materials, people and products. Additionally, any transportation of products, parts or materials may be a potential source of damage for items themselves.

Processing. Adding unneeded steps to the process is a source of waste, similarly, producing higher quality product than needed (*over processing*) is considered as source of waste. This type of waste derives from insufficient product design or unsuitable machinery.

Inventory. The higher is the number of items (materials, components or products) in the inventory, the higher will be costs associated, in terms of higher throughput times, higher transportation and storage costs. Furthermore, a high level of inventory in general indicates problems in the process as unbalanced production capacity, delays, unused equipment and all related defects.

Motion. As seen for transportation waste, all non-necessary movements, including walking, lifting, reaching, bending, stretching, and moving, should be eliminated from the production process. Also in this case, poor layouts design or structures lead to unproductive actions and in turn to waste.

Defects. All repairs, reworks, reproduction, modifications and inspection are all activities which do not add any value to the final product, and for this reason are considered waste. The reason behind defects is primarily a poor quality of the production process. Defects implies a financial loss because of the non-conformity; moreover, they generate additional cost because of the extra work, material and equipment.

Even though it was not included in the original TPS, when in 1980s this concept was extended also in Western part of the world, an additional waste was introduced, as shown in the .

Human potential. This waste indicates the separation of managerial duties and position from employees, which leads to non-utilisation of skills and talent of workers. In some organizations, employees are only entitled to follow orders and execute tasks as intended, hence excluding the possibility of improving the process adding their knowledge and ability: people that are directly involved in the process are most capable of identifying problems and therefore developing solutions for them. Examples of waste of human potential include insufficient training or inadequate equipment and poor incentives for innovative ideas and solutions.

Figure 6 Eight Wastes (Source https://www.automationmag.com/7872-seven-wastes-of-lean-and-how-to-eliminate-them/).

There are plenty of causes for the previously reported wastes; examples are the inadequate layout, in a poor maintenance or production process, in the lack of training or motivation of employees, in incomplete planning and design of either product or process.

In addition, Muda are not the only elements that may create problem within a process; in fact, it is possible to identify other two additional "MU":

Muri. It is a Japanese term indicating the overload of people or resources. Excessive fatigue of workers may increase the possibility of accidents or diseases, causing general delays and interruptions. Similarly, over-exploitation of machinery can lead to wear and breakups, resulting in maintenance and repair, or in the worst case in need of new machine.

Mura. It indicates fluctuations, variation, particular workload (in the demand). This leads to an alternation of overload of work (*Muri*) and of unused capacity (*Muda*).

2.3.2.2 TPS Foundations

At the base of the TPS House, it is possible to find four main elements: *Heijunka,* Standardized Work, Visual Management and *Kaizen.*

Heijunka is a Japanese word that means “leveling.” According to *Lean Lexicon*, Heijunka can be defined as: “Levelling the type and quantity of production over a fixed period of time. This enables production to efficiently meet customer demands while avoiding batching and results in minimum inventories, capital costs, manpower, and production lead time through the whole value stream.” This means that production levelling balances the workload within the production process while minimizing all possible fluctuations *Mura*, which in turns is crucial to reduce *Muda*. The idea behind Heijunka is to produce upstream components and items at a constant rate so that also downstream processing can be performed at constant and predictable rate. When considering Heijunka, it is possible to distinguish between levelling by volume or levelling by production mix. Production levelling can be applied to volume, product type or a joint levelling of both volume and product type. In the former, the average of demand is computed to define the minimum production batch, with a minimum level of inventory able to satisfy any possible peaks; monitoring both the average demand and the initial stocks, enables to level production. Whereas in the latter, in order to coordinate different products with different stages of processing, it is possible to include all the different products in a single set and then organize batches and inventory according to the reference mix; considering all products in a single set allows to maintain the same level of productivity, avoiding that a single product exceeds the average production of the others.

Standardized work. Standardized work refers to all the procedures carried out within a business, from the production ones to the administrative ones. It promotes stability, which is essential for improvement. When dealing with standardized work, it is necessary to not be confused with the use of standards; work organized in an efficient sequence is a standardized work. Standardized work requires the application of three main elements: Takt Time, Working Sequence and Stock. *Takt Time* is an estimation of the rhythm of production, since it is defined as the time required to produce a single component or the entire product, based on customer demand; it is important to stress that takt time is reliant upon customer demand, since its computation implies understanding how activities and processes should be organised to meet customer demand. Takt Time should not be confused with Cycle, defined as working time of the process (to complete one product). *Working Sequence* indicates a unique sequence of operations to be processed and the manner of performing them. *Stock* refers to the minimum level of inventory needed for production, which ensures the continuous execution of the production process.

Visual Management. This method allows the visualisation of progress in a business progress, toward the use of simple tools. The aim is to provide all the information regarding progress, stressing all eventual challenges and problems, in order to face them promptly. Main tools of Visual Management can be divided in three main groups, depending on function and type.

Viewers. This category includes all graphs and diagrams functional for the execution of work, very useful, especially in complicated or unusual problems. Viewers can also stimulate performances, showing goals and results to achieve.

Visual controls. Visual controls give instruction on timing and manner of given task. Especially in a production process, they can be used to guarantee safety and coordination (Example of a traffic lights, where the green indicates starting or ongoing activity, while red light indicates the stop of the activity).

Visual process indicators. In general, they are very simple stratagems, to mark areas and process, guiding in a quick and intuitive way the correct flow of materials or information.

The last, but most important part of the foundations is *Kaizen* (改善). The Japanese term is composed by the term *Kai* (improvement, change) and *Zen* (better), which means *change for better*, or as it is widely known *continuous improvement*. Kaizen was introduced after World War II, when Toyota's workers, in order to compete with American car makers, started to focus on preventing defects. Subsequently, the term was used for the first time by Masaaki Imai to describe philosophy behind Toyota's success of 80s (Imai, 1986). Once understood the power of Kaizen, it has been adopted in different situations, from personal life to any type business, including healthcare (Weed, 2010).

The goal of this concept is improving quality, through elimination of waste and defects, promotion of innovative ideas and motivation of employees. The underlying hypothesis in the application of the Kaizen is that everything can be improved, since in every activity or process is possible to discover waste and inefficiencies, thus, there is always an opportunity for a small, but continuous improvement (Jeffrey Liker & Gary L. Convis , 2011). As consequence, Kaizen does not involve huge investments, but it requires to optimize available resources, through elimination of waste. In order to successfully apply Kaizen, it is necessary a high level of cooperation within the company and a direct involvement of all the levels of the hierarchy, especially the lower ones; for this reason, it differs from top-down management approaches, since decisions or modification must come from the bottom and ordered by top management as in other managerial technique.

The implementation of Kaizen requires elevated levels of process engineering: the first step is getting employees involved and sharing company's vision; then, it is necessary to find problems in the process, in order to see all possible issues and opportunities of improvement. Once understood what the problem is, solutions have to be created and implemented, for instance using problem solving techniques as the *5 why's* introduced by Sakichi Toyoda (Ohno, The Toyota Production System: Beyond Large-Scale Production, 1988). When solutions have been identified, they must be tested and results analysed to prove their validity; only in case results are positive and successful, solutions are standardized and they are repeated, becoming part of the process. Similarly, the Deming or Shewhart cycle, also known as *PDCA Cycle*, is an iterative method used to focus on quality improvements (Tague, 2005). As shown in the

***Figure 7**,* PDCA is the acronym of Plan-Do-Check-Act, the four steps of the cycle: in the planning phase, it is necessary to analyse information and data to set goals and objective from a strategic point of view; in the do phase, the plan created in the previous phase must be executed; in the check phase, work performed must be monitored and results obtained through execution of the plan analysed; finally, in the last phase, the act phase, problems occurred should be corrected and prevented.

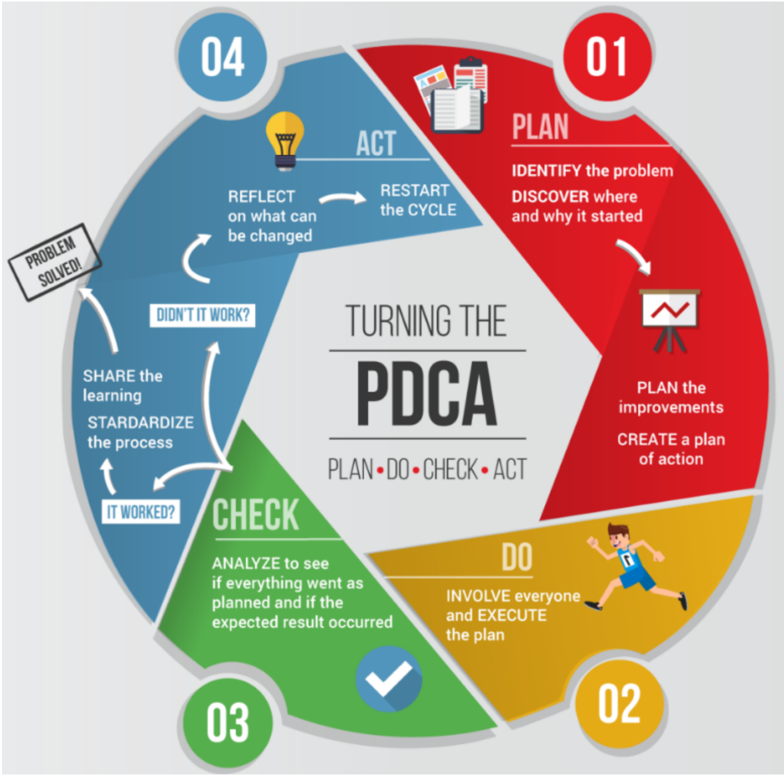


Figure 7 PDCA Cycle (Source: https://www.siteware.com.br/en/ methodologies /what-is-the-pdca-cycle/)

Another technique used in order to achieve Kaizen is 5S Framework, which, through a specific mindset based on order, organization, cleanliness and standardization, increases profitability and efficiency, thus providing more value; the name 5S derives from five Japanese terms representing the main phases of the method.

Seiri (Sort). Select only items that are necessary to complete work; the ones that are not used for the work are removed from the workplace.

Seiton (Set in order). All items must be organized and properly placed, in order to make easier completion of work.

Seiso (Shine). This phase requires cleaning and maintenance of the organized workspace.

Seiketsu (Standardize). Organization and process must be standardized, through the creation of set of rules and practices.

Shitsuke (Sustain). The activities done in the previous phases must persist and become part of the routine.

Figure 8 5S Lean Framework (Source: http://www.leanevolution.com)

In short, the idea of small continuous changes provides a softer approach with respect to big efforts required by radical changes, thus reducing tendency to resist to changes; on the other hand, short-term excitement for Kaizen cycle may not last, therefore, the Kaizen itself may not be successful. Moreover, in Kaizen mistakes and waste are reduced, and as consequence also costs for controls and inspections are reduced. Finally, Kaizen promotes cooperation and teamwork, encourages and motivates employees in pursuing their ideas and in thinking beyond the specific task; for this reason, as prerequisite for implementing Kaizen companies must create a communicative environment.

2.3.2.3 TPS Pillars

The two pillars of the TPS, representing the core of the production system, are Just-in-Time (JIT) and Jidoka.

Just-in-Time refers to an inventory management system, in which components/materials are available in the right quantity at the right time (Ohno, 1988). Indeed, the system is demand-drive, meaning that the company produces only what the customer actually orders, and not what is forecasted. As consequence, producing only necessary units lead to reduction (ideally, elimination) of stocks and its related inventory costs; in addition, it enables a better management and allocation of company's resources. In JIT philosophy in fact, inventory is seen only as an additional cost, which does not provide any further value; moreover, as previously mentioned in *Inventory Waste*, a high stock level is seen as a poor management, since it points out problems within the production system (Liker, 2004).

The JIT philosophy is usually used in conjunction with *Single-Minute Exchange of Die* (SMED) technique, which allows production of smaller batches, by means of rapid set-up times. This method is useful especially for production process with low flexibility or with capacity problems. In JIT philosophy it is possible to identify three main concepts: *Takt Time, Continuous Flow* and *Pull System*. The first concept has been already introduced when dealing with *Standardized Work,* in paragraph *2.3.2.2.*

Continuous Flow. Continuous flow, also called One-Piece-Flow, is a way organizing products, such that a single product is moved through every step of production process instead of batches of products, to be processed. In this way, the single piece moves from one operation to the other, avoiding build-up of materials between workstations, thus reducing the total time of the production line (because of the reduction of waiting time of each part) and providing more value to customers.

Pull System. Pull system is a production system in which production is based on actual demand (for this reason is pulled by market), and where information flows to company, opposed to traditional push systems, where production is based on forecasted data and does not reflect actual demand. This system is usually implemented using a *Kanban* (namely tag in Japanese) system. The Kanban is a visual instrument (usually a card, a signal, a mark) reporting a series of information and instructions; as reported in ***Figure 9***, it generally contains an identification number of the part/products, a brief description of part/products, order and due date and the identification of the supplier.

Part Description				Part Number	
Smoke-shifter, left handed.				14613	
Qty	20	**Lead Time**	1 week	**Order Date**	9/3
Supplier	Acme Smoke-Shifter, LLC			**Due Date**	9/10
Planner	John R.		Card **1** of **2**		
			Location	Rack 1B3	

Figure 9 Kanban Card (Source: https://www.velaction.com/kanban-card/)

It is possible to distinguish two main type of Kanban cards:

Production (P) Kanban: It represents the actual production order, which allows the downstream workstation to produce a specified quantity of component/product. These tags are used only at the production units.

Transportation (T) Kanban: It authorizes movements and transportations of components/materials through workstations in the production process. It reports types and quantities of components needed, in order to record usage between different stages.

David J. Anderson, one of the main experts of Kanban knowledge, identified six fundamental principles for implementing the system (Anderson, 2010).

Visualise the workflow. The first step is understanding the flow, from customer's request to the final deliver of product; the knowledge of all stages within the business is essential for identifying opportunities and challenges. Generally, the visualisation is made through a board, as in the ***Figure 10*** below, in which each column represents a stage in the workflow and each Kanban tag is an item to be processed (a request).

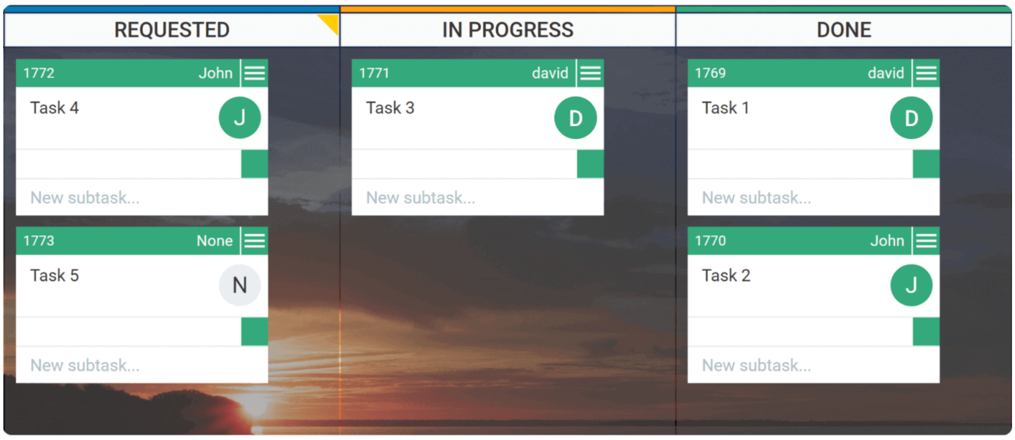


Figure 10 Board Kanban Visualisation (Source: https://kanbanize.com)

Limit Work-in-Progress. Kanban must guarantee a reasonable number of ongoing items at time. Limiting WIP ensures that the item is pulled in the next workstation only if there is available capacity.

Manage Flow. Controlling the flow means understand the process and the system that executes it; this will help in recognize criticalities and bottlenecks, thus allowing a faster and smoother production flow.

Explicit Process. The process should be clearly defined and described, in order to avoid misunderstanding or problems related to information.

Feedback Loops. The Kanban philosophy promotes knowledge exchange through daily meeting, in which employees declare work scheduled for the day.

Improve Cooperation. The key in a successful implementation is a shared vision and collective understanding of the challenges to be overcome and the goals to be achieved.

In a nutshell, Kanban provides lots of benefits because of the transparency of the environment in which every employee works, since all operations and task are visually displayed through a board; the latter makes easier the identification of bottlenecks in the workflow. Furthermore, Kanban allows a higher flexibility and responsiveness, since it is derived from market information and request. Finally, it boosts productivity, enhancing collaboration and teamwork, thanks to the shared vision of continuous improvement.

The other pillar of TPS House is *Jidoka*. The meaning of this term is very peculiar; the original word was 自動化 and means automation (自 for self, 動 for motion, 化 for the action of making something). Toyota changed the middle kanji from 動 to 働, as shown in the ***Figure 11***, meaning work or labour. The translation of the new word 自働化 is usually confused with “automation”, even though Toyota’s meaning is closer to “auto*no*mation” or “automation with a human touch”, to stress human importance to create more value.

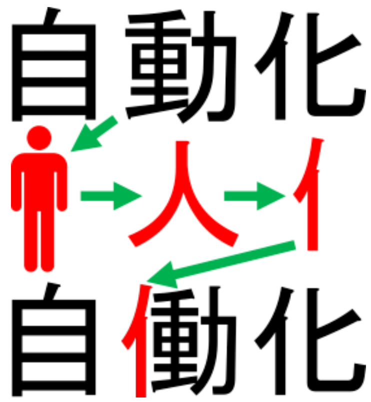


Figure 11 Origin of Toyota Jidoka Kanij(Source:https://www.allaboutlean.com)

The concept of Jidoka was introduce by Sakichi Toyoda, through the invention of the automatic textile loom, that stopped when any thread broke. Previously, if a thread broke the loom would churn out mounds of defective fabric, so each machine needed to be watched by an operator. The main objective of Jidoka is ensure high quality process, by providing machines and workers the ability to detect abnormalities and immediately stop work if something is found. In other words, the process is stopped only when the imposed quality level is not guaranteed, since machines are equipped with stop devices and workers are empowered to stop production for non-quality situations.

Each item is controlled by operators, often using *Poka Yoke* process; this term defines fool proof procedure, preventing formation of defects. It is possible to identify three methods of Poka Yoke: *Contact Method*, in which physical features as shape, colour allow discover of right position and right connections. *Fixed-*

value Method, in which the number of operations is tracked. *Motion-step Method*, in which the execution of different stages is controlled and examined.

2.4 Six Sigma

Both Lean management and Six Sigma are used to eliminate all inefficiencies and consequently to improve. As explained in previous paragraphs, Lean principles aim reduce waste and increase productivity, which in turns save costs. Six Sigma principles seek to increase the quality of product by identifying and eliminating all possible causes of defective products and reducing variability of whole process. This methodology uses mainly statistical and data-driven to achieve same goals of Lean management.

Six Sigma is a quality-control methodology developed and registered under a trademark in 1986 by Motorola[3]. The idea behind Six Sigma is that by measuring the quantity of "*defects*" identified within a process, it is possible to systematically discover how to eliminate them and approach as much as possible to "*zero defects*"; the term derives from the dispersion of a process around its average value: in fact, in case of a bell shaped normal distribution, there is 99.97% probability that a value will fall within of the range between $\pm$ 6 sigma, therefore a Six Sigma is intended as a process in which defective parts will be only 3.4 per million of pieces produced (or service provided) randomly and normally distributed, insisting that 99.97% of its products or services are without defects.

2.4.1 Origins of Six Sigma

Six Sigma was born from different theories of quality control. In particular, W. Edwards Deming, an American statistician travelled during 50's to Japan to teach his techniques of statistical process control. The key of Deming's belief was that only though observation of process and record of data was possible to identify defects and problems in the production process, thus implementing an efficient quality control method. By the 1970s, Japanese automotive and electronic

[3] https://trademarks.justia.com/741/99/six-74199225.html

industry surpassed American products both in quality and reputation. Later in 1986, Bill Smith, a Motorola engineer, developed the Six Sigma program aiming at improving quality and reducing defects in their products. The top management of the company was impressed by the success of this new technique and under Motorola started to apply Six Sigma across the whole organization. Motorola's implementation of Six Sigma was extremely successful; as reported by Dharmendra Tyagi et al. (Dharmendra Tyagi et al., 2014) the reduction of defects on semiconductor devices was estimated for 94% between 1987 and 1993.
In the early 2000's, General Electric passed Microsoft to become the world's most valuable company. The giant, selling a wide variety of products from jet engines to advertising, was directed by a dynamic CEO, Jack Welch, who truly believed in the power of Six Sigma. Because of its powerful application, in 1995 General Electric adopted Six Sigma, becoming a corporate religion: the company made huge investments for training personnel and applying the Sis Sigma throughout the company, emphasizing the efficiency of this technique.

2.4.2 Basic of Six Sigma

The theory states that standard deviation of a process must not exceed a given threshold with respect of the specifications. From a practical point of view, the Six Sigma is a rigorous application of statistical techniques and quality principles, aiming at increasing efficiency of entire performance, so that the process is, at least ideally, free of defects.

The implementation of Six Sigma methodology relies on the DMAIC model, which is followed for every problem the company must face; this model consists of 5 phases, namely ***D****efine,* ***M****easure,* ***A****nalyse,* ***I****mprove* and ***C****ontrol*.

Define. In the first phase, it is necessary to find the process or product features to be improved, by translating customer's needs into requirements, identify different stakeholders involved and set goals to be achieved and the scope of the work. Generally, in this phase main tools to be used are Gantt and flow diagram, project charter and Pareto charts.

Measure. In this phase, the problem previously identified is translated quantifiable, as-is performance is assessed and compared to starting requirements. To do so, it is necessary to find a suitable measurement system and only after it has been validated, measurements ca be taken and results obtained can be compared with required values, in order to get the current level of sigma. Tools used in this phase include descriptive statistics, sampling and repeatability-reproducibility test (Gage R&R).

Analyse. Based on measurements, statistical techniques must be adapted to identify the causes of defects and to quantify the impact of each cause on the requirements and its variance. In this step, there is a long list of means to be used, such as the analysis of variance, in short ANOVA, Pareto chart, regression and correlation.

Improve. In this step, improvements are defined and implemented. This is the stage at which improvements are proposed and enforced, only after complete comprehension of causes of defects; the latter is a key point in the application of Six Sigma, before directly test solutions, it is crucial to have a full understanding of roots of possible failures. To choose the solution to implement, different techniques can be use as FMEA (failure modes and effects Analysis), DOE (Design of experiments - Experiment design) and Cost-benefit analysis.

Control. In the last stage, the process is observed, in order to standardize the new changes. Moreover, the effectiveness of improvement is measured, also in relation with a quality diagram or quality control plan, previously outlined by the company, and adjustments are taken for drafting the final procedure.

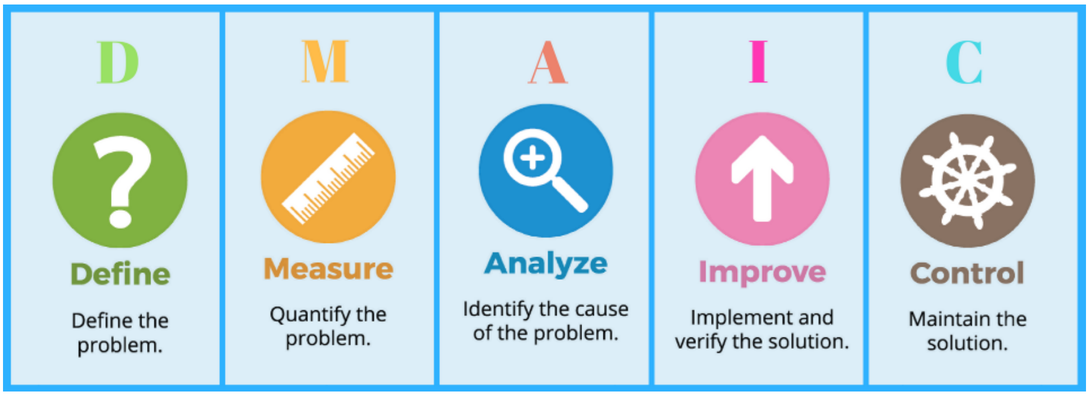


Figure 12 DMAIC Framework (Source: https://www.msystraining.com)

This DMAIC can be adapted also to new processes, by slightly modifying different phases: in the define phase, it is necessary to include the possibility that the new product or service does not meet customer’s expectations; in the measure phase, similarly, the process is measured so that it verifies customer’s need; in the analyse phase, there is the analysis of the options needed to satisfy customer; the next phase in the method are *Design* to modify the process so that it exactly meet customer’s needs and *Verify* to see if changes made have aligned customer’s need with the process. The method is so converted in the DMADV.

2.4.3 Six sigma or Lean Management?

Six Sigma is an evaluation process used to identify weaknesses and improve the overall process, starting from improving quality of the production process. Lean manufacturing is similar, but it is more concerned on elimination of waste and reduction of non-utilisation of resources. The first difference can be identified in the focus for the identification of the problem: while Lean is mainly focused on eliminating wastes, Six Sigma’s priority is the reduction of the variation, seen as any deviation from the target performance.

Another major difference is that Six Sigma process is based mainly on statistical techniques and does not necessarily focus on the role of teamwork, for this reason it is said to be data-driven technique. By focusing on quality of output, Six Sigma enables the company to achieve nearly perfect results, thus reducing costs and increasing customer’s satisfaction. Lean manufacturing instead links the top management with workforce through communication, to enrich performance and improve processes. In fact, in the Lean perspective the knowledge of each employee is a valuable resource to understand the process and the workflow, therefore crucial for increasing efficiency and finding correct solution.

Although Lean and Six Sigma have some differences, they both share the same goal: eliminate waste and create value by improving processes. Therefore, in recent times, these two methods have been used jointly –under the name of Lean 6s— to maximize benefits. It combines practices, approaches and principles of Lean and Six Sigma into one powerful strategy for enhancing the company. There are three key elements to Lean Six Sigma. The first element is a complete set of tools and techniques, needed for discovering and solving problems. Then, the second element required is a precise methodology, consisting of a series of procedures to enable that a solution can be found and fully implemented. Finally, it is necessary to spread throughout the company a mindset ensuring the continuous improvement. These three elements increase their efficiency when used in conjunction. The similarities among Six Sigma and Lean allow the maximization of their combination. Both methods are based on customer's perception of value; moreover, they rely upon the understanding of the current process behind the creation of the product or delivery of the service, which are crucial for determining future possible improvements. Finally, both derive from the manufacturing industry and are now adapted to different type of industry and different operations.

Chapter 3 Lean Healthcare

The need for an efficient and more dynamic services industry arose primarily from the growing weight of services in OECD economies[4]; day by day, the world is moving toward an even more *service-oriented* approach. Consequently, Lean concepts have been adapted to the service sector to achieve the same results obtained in manufacturing industry: improve process, thus reducing costs and increasing customer's value. The analogy between service industry and manufacturing industry in terms of Lean management can be undertaken if the product purchased by customers is considered in terms of benefits provided, rather than its economic value (P. G. Nicosia, F. Nicosia, 2008). However, when dealing with service sector, it is important to stress three major differences with respect of manufacturing sector. Firstly, services may be considered as intangible goods, therefore it becomes more difficult to discern how customers value services. Secondly, services are characterized by a higher variability than production of goods; this increases difficulty in standardization of processes. Lastly, the organization of a service company is deeply influenced and altered by customers and their behaviour, because patients do not perceive only the quality of final outcome, but of the whole delivering process, which in turn decreases the ability of company to manage and control quality (A. Parasuraman et al., 1985). In addition, services are utilised in the same moment in which they are delivered, thus making impossible modifications or rework, as in case of manufacturing sector.

In the healthcare environment, as seen for the automotive industry, the introduction of lean practices is aimed at improving the output provided, which in case this specific case means increasing the quality of patient care and reducing utmost any waste of resources, either personnel or equipment. It is possible to summarize three main goals of Lean Healthcare: *improvement of process* – in order to achieve higher efficiency, especially in the usage an allocation of resources; *increase patients' satisfaction* – aimed at delivery of high-quality

[4] Growth in services- Fostering employmeng3wt, productivity and innovation – © OECD 2005

service; *reduction of medical risk* – as consequence of reduction of variability of processes.

The application of these practices seems to be successful for healthcare organisations, since strengthened by the increasing number of implementations in literature. The precise date of the first application of lean in healthcare is uncertain; although not expressly in terms of Lean, Heinbuch (1995) started to consider a *transfer of technology*, reporting the application of just-in-time lean concept in health care, to reduce the impact of inventory in hospitals. However, evidences presented in literature (Brandao de Souza, 2009) suggest that implementation of lean appeared nearly 2000, first in UK, in a work published by NHS Modernisation Agency (Agency, 2001) and then in USA, at the end of 2002, as implemented by Virginia Mason Medical Center, in response to financial constraints that healthcare faced in those years.

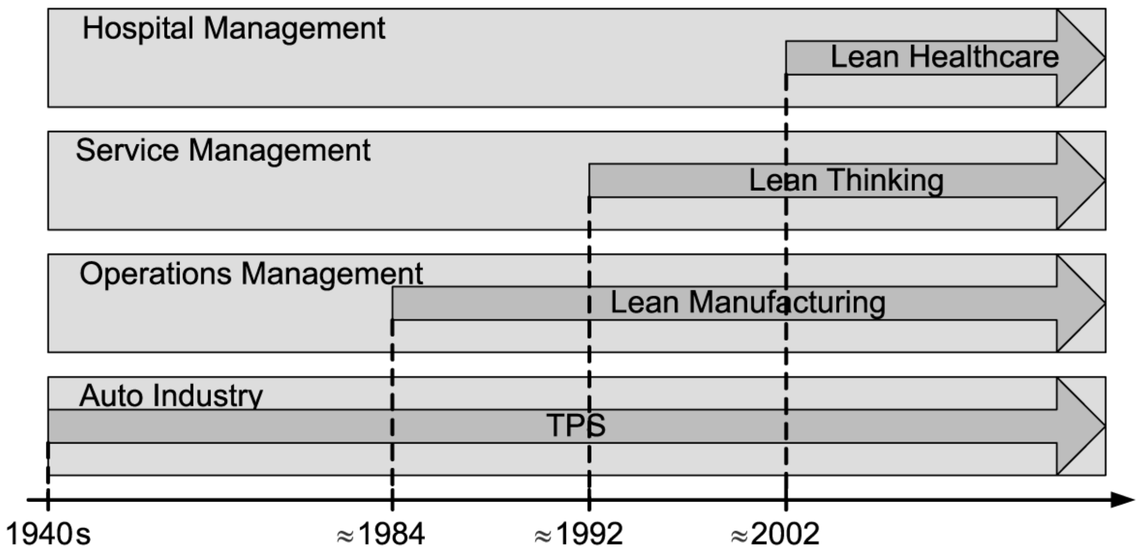


Figure 13 The appearance of Lean Healthcare (Source: Trends and approaches in lean Healthcare, L. Brandao de Souza, 2009)

Figure 13 highlights a ten-year delay in the application of lean healthcare, when compared to other industries that provide service (Brandao de Souza, 2009). There are a few reasons behind this delay in the spread of lean concepts; first, as previously mentioned for the service industry, healthcare environment is characterized by high variability, which may derive from organization and management of service –in this case it is named artificial variability – or reliant upon clinical aspects, as individual's response to treatments or disease course, defined indeed as natural variability. It is clearly thus that while the latter cannot be reduced, since depends on different factors which cannot be managed, the former represents the work field of Lean Healthcare. Notably, this type of variability is divided in three macro-categories: *layout, process variability and staff variability* (P. G. Nicosia, F. Nicosia, 2008). Another critical aspects is the complexity of healthcare system; thereof is composed of different professional groups, with various roles and different power and it is subject to external regulatory bodies, which in turns increases time needed for quality improvement to be successfully implemented (E.Ferlie and T. McNulty, 2002). Moreover, healthcare facilities are generally structured according to a hierarchical or functional organisation; in this way, patients flow toward the hospital is difficult to manage, since it may involve different units and departments; as consequence, it increases obstacles to identify and improve patients' value (P. G. Nicosia, F. Nicosia, 2008).

On the other hand, what makes Lean management suitable for innovating healthcare system is essentially related to the common attention to quality, usually expressed in terms of zero defects, and the importance of staff empowerment and involvement; moreover, in a sector characterized by increasing funds reduction, the utilisation of lean practices does not require substantial financial support and its flexibility allows the application to any possible situation. As reported by Z. Radnor in the article *Implementing Lean in the Health Care: making the link between approach, readiness and sustainability*, published on the *International Journal of Industrial Engineering and Management* (2011) the implementation of Lean projects in the healthcare context leads to some important results, either quantifiable, as the reduction of processing time for some particular clinical paths, costs reduction and an increase of productivity, or qualifiable results, as the decrease of chances to make errors, improvement of atmosphere of work place and increase of patients' satisfaction.

Although the growing number of applications of lean concepts in healthcare, the literature highlights that lean tools and methods are applied, in the majority of cases, to small projects or single units/departments, revealing the lack of commitment for the implementation of an integrated approach to healthcare context (Souza, 2009) and , consequently, limiting the efficiency of lean in the improvement of processes (Radnor, 2011).

3.1 Lean framework in Healthcare Sector

Implementation of Lean Healthcare has been divided by Radnor and Walley (2008) in two classes, based on the perspective of their application: *Rapid Improvement Events (RIEs)* and *Long-Term Strategic Events.*

Rapid Improvement Events (RIEs). In the first class, lean concepts are applied for a limited period of time (generally one or two weeks), and they are focused on the improvement of specific part of the hospital, a specific unit or department. The main advantage of RIEs is the rapid achievement of important outcomes, however their sustainability on a long-term perspective is limited, especially when these lean techniques are misaligned with the strategic view of the company (C. Bianciardi et al., 2004).

Long-Term Strategic Events. Under this class instead, lean philosophy is embedded inside the company, through the definition of a new strategic view, which reflects lean concepts. The aim is the sustainability over time of improvements, with a systematic implementation of lean techniques.

Although it is clear the theoretical distinction between RIEs and long-term events, in practice it is not possible to fully distinguish between two approaches; in fact, it has been observed that lean events may start as rapid improvements and then turn into a long-term strategic event (C. Bianciardi et al., 2004).

Once decided the approach to be adopted, lean projects require some crucial features to be achieved, as prerequisite for a successful implementation (C. Bianciardi et al., 2004). As first prerequisite, it is necessary to inform and educate all people involved in the project to lean principles and tools, in order to increase and facilitate their motivation and active participation to the project. Another essential element is the definition of a lean team, which can be seen as a reference point in the implementation and as continuous source of motivation for the sustainability of project over time. Finally, the role of leadership. Top management must be committed in the implementation of lean strategies, supporting the application of lean and providing all necessary elements needed for the implementation. According to lean idea of small continuous improvements, rather than addressing the big picture, the winning idea is to start by directing on the small inefficiencies, which are more likely to be identified and faster to be solved. This is because fast successes generate satisfaction, motivating personnel in addressing bigger challenges and increasing participation (C. Bianciardi et al., 2004).

3.1.1 Lean principles and tools

As introduced in the previous chapter, Lean management is focused on the concept of value, which is prerequisite for the life of every company, independently from the sector; in the healthcare context, the definition of value merges what is valuable form the customer's perception with the achievement of an adequate health care outcomes. Similarly, to what introduced in previous chapter, any process that does not increase this value can be considered as waste. Those are the key notions for a successful implementation of lean practices; once defined what value is and what contributes to its creation, it is possible to improve the organisation through the elimination of non-value-added activities.

The seven (plus one) wastes provide useful guideline for identify all possible sources of waste, which may be evidences of a problem within the system or organisation. The translation of these concepts from high-volume production to service environment, and similarly to healthcare context, is not immediate; Bicheno and Holweg (2009) proposed for the service industry an interpretation of seven wastes as reported in ***Table 2*** below:

Table 2 Service industry: interpretation of seven wastes (Source: Robinson et al./ European Journal of Operational Research 219 (2012) 188-197).

Original manufacturing wastes (Ohno, 1988)	Service Wastes (Bicheno and Holweg,2009)
1. Transportation: moving products that are not actually required to perform the processing	*Delay* on the part of customers waiting for service, for delivery, in queues, for response, not arriving as promised.
2. Inventory: all components, work in process and finished product not being processed	*Duplication*: having to re-enter data, repeat details on forms, copy information across, answer queries from several sources within the same organisation.
3. Motion: people or equipment moving or walking more than is required to perform the processing	*Unnecessary movemen*t: queueing several times, lack of one-stop, poor ergonomics in the service encounter.
4. Waiting (Delay): waiting for the next production step	Unclear Communication and the wastes of seeking clarification, confusion over product or service use, wasting time finding a location that may result in a misuse or duplication.
5. Overproduction: production ahead of demand	Incorrect Inventory: out-of-stock, unable to meet exactly what was required, substitute products or services.
6. Over- or inappropriate processing: resulting from poor tool or product design creating activity	Opportunity Lost to retain or win customers, failure to establish rapport, ignoring customers, unfriendliness, and rudeness.
7. Defects: the effort involved in inspecting for and fixing defects	Errors in the service transaction, product defects in the product-service bundle, lost or damaged goods.

Accordingly to the classification of Ohno, NHS Improvement adapted in 2007 these concepts, providing examples of wastes in the healthcare environment:

Transport. Waste of transport refers to the excess movement of the product, medical documents or supplies and equipment through the process. Some of transportation will be necessary because of the layout of the facility, but it is necessary to re-design the flow of different actors optimizing and minimizing transportation. Examples are transfer of equipment from one end to the other of the ward or movements of medical reports from one room to another.

Inventory. In this case, having more items than necessary creates inventory, considered as waste, since they absorb costs and resources: as inventory increases, also space required to store them increases, leading to higher storage costs and to additional transportation waste and to possible damages of items. Typical examples are underutilisation of resources, as empty operating rooms. Another way to think of inventory waste in healthcare is considering patients as items that move from one working station to another, hence the number of patients waiting to be discharged or the waiting lists represents the stock level, which must be carefully managed.

Motion. Generally, the term motion indicates the movement of employees. Those movements can be divided into useful movements, necessary for the execution of process and un-useful movements, which should be reduced and eliminated. Walking is the commonest type of motion waste, as walking for asking an advice to a colleague.

Waiting. Waiting refers to waste of time between one process and another or within process itself, which clearly decreases productivity. Patient waiting rooms, medical records waiting, lack of information necessary for process –as particular tests, equipment and instruments waiting to be sterilised to be used are some examples of waste in healthcare context.

Over production. This waste indicates the excess of a product or service provided, which, as consequence, increases costs and waste of resources. In healthcare context, it may be represented by replication examinations to be taken before a given exam or request of un-necessary diagnostic procedures, higher number of meal or equipment than needed, for instance for patients already discharged or hospitalisation longer than necessary.

Over processing. Doing superfluous work or delivering higher quality services is considered a waste. In this case, executing manually activities that can be done also in an automated way or preparing equipment which will not be used are examples of waste. In the healthcare settings, as previous type of waste, this is mainly caused by the lack of efficiency in the process design, resulting in duplication of activities and processes.

Defects. When considering healthcare, defects are not simply products that un-met required quality standards; defects in case of patients are damages and consequences of wrong diagnosis or treatments. An example is the situation in which a disease is not detected, leading to a wrong diagnosis and treatment, which increase costs, since patients must re-take medical tests and hospital must face all possible legal disputes, deriving from the undetected problem.

Human potential. The last type of waste, not originally included in Ohno's theory, refers to poor utilisation of human resources, because of excessive division of activities, lack of satisfaction and involvement of employees in valuable activities.

Another fundamental concept is the notion of flow. It is possible to define within the hospital different flows, which should be taken into consideration when implementing lean (Black, J. ; Miller, D., 2008). These are the following:

Patient flow. The patient flow can be considered as the path of patients through the hospital, from their arrival to the final discharge, which in turns quantifies the time spent by patients within the hospital. Considering a generic patient journey, it is evident the number of stops and delays affecting different activities, thus increasing dramatically the length of stay of patients. An accurate re-design of processes is needed to speed up the flow of patients and reduce length of stay at the hospital.

Clinical flow. Physicians, nurses and other actors move within the facility to complete all their tasks. Staff movements must be reduced at minimum possible to guarantee that time will be spent in patient care rather than in movements towards the facility. The efficiency of this type of flow is mostly affected by layout of the facility, which should be designed properly.

Pharmaceutical flow. Drugs and medicines are continuously transferred toward the department. The point is having the correct amounts of the correct drugs at the right time for the right patient. Of course, the digitalization of drugs usage and consumptions is improving the entire pharmaceutical flow.

Medical device flow. Medical devices are needed in different areas of the hospital. Their flow is similar to the one of pharmaceutical goods, but requirements and utilization are different.

Information flow. Nowadays, strictly related to patient flow, an amount of information is recorded and stored in specific information systems, in order to be easily accessed by different departments or even from different hospital. It necessary to have complete, consistent and ready information when needed, to avoid all possible delays or inefficiencies. This could not be possible without the use of an information system that records and presents the right information at the right time.

Medical equipment flow. The use of medical equipment is fundamental in case of specific healthcare departments, as surgery. Their flow must be taken into consideration when planning surgeries or exams that requires specific equipment. Moreover, a right sizing is needed to facilitate their transport, reducing risks of possible damages.

Once translated in healthcare term the key ideas of value and flow, it is possible to focus on different tools of Lean philosophy used. Depending on their area of application in the healthcare context, lean activities can be divided in three main categories: *Monitoring, Assessment and Improvement* tools (S. Robinson et al., 2012).

Monitoring. Monitoring tools are used to evaluate and control the processes and their progresses, to support the usage of visible information, which are helpful in sharing results, and to identify possible errors occurred within the process. Generally, these tools include Kanban, Poka-Yoke and especially Visual Management tools. It has been proven (K. Silvester et al. , 2004) that the introduction of monitoring tools in healthcare settings promotes reduction of waiting times, increasing efficiency of emergency departments, intensive care and operating units.

Assessment. Assessment tools are used to evaluate and revise the current performance of different processes, regarding their ability to increase value and their aptitude to produce wastes; specifically, they are used to determine the grounds behind wastes and inefficiencies. Assessment tools include *Spaghetti Diagram, 5why's, Failure Mode Effects and Criticality Analysis FMECA* and *Value Stream Mapping*. The latter is the most utilised tool when considering Lean Healthcare (Polinska, 2010).

Improvement. Lastly, improvement tools are used to promote improvement and enhancements of processes. They generally involve activities aimed at re-designing procedures, modifying layout or other operational aspects, or evaluating personnel. Main tools of this type are *Rapid Improvement Events* (RIEs) or *5S* technique.

3.2 Taxonomy for lean healthcare literature

Reportedly Brandao de Souza (2009) in his review, publications referring application of lean technique in healthcare context can be divided in two categories: *Theoretical* and *Case Studies*. While the latter includes papers based on an actual implementation, the former focuses on theoretical work, not based on practices. ***Figure 14*** shows the taxonomy proposed by the author, theoretical papers are divided into *Methodological* or *Speculative,* whereas Case Studies are classified accordingly to their field of application and they can be: *Manufacturing-like, Managerial & Support, Patient Flow and Organisational.*

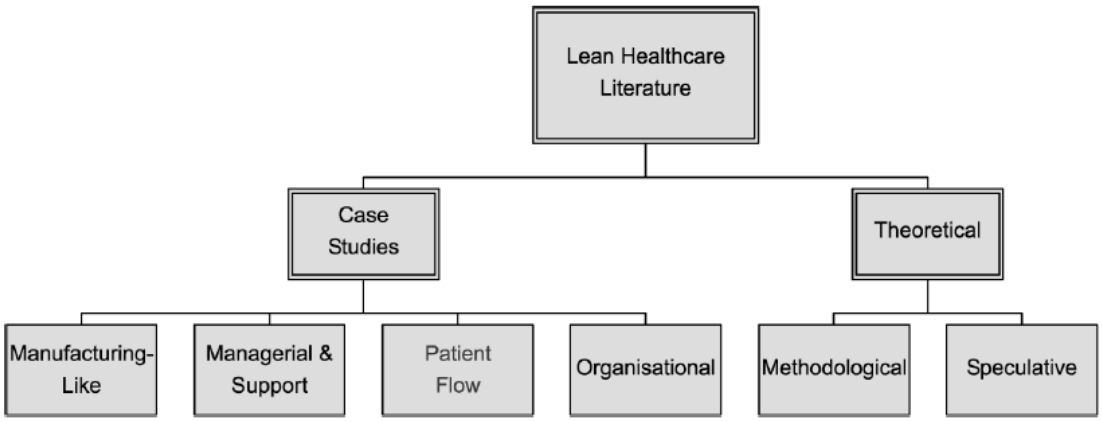


Figure 14 Taxonomy of lean healthcare literature (Source: Trends and approaches in lean Healthcare, L. Brandao de Souza, 2009)

3.2.1 Theoretical

As previously mentioned, theoretical works are divided in *Methodological* or *Speculative.*

*Methodological***.** Methodological publications focus on methodological discussions, aiming at providing new productive effort, new approaches either for the implementation or the integration of actors in terms of long-term strategic decisions, discussing methods to overcome any possible obstacle in the application of lean.

Speculative. In this case, the main goal is the interpretation of lean concepts in terms of healthcare context, aiming at understanding and investigating their potential usage, and case studies involving patient flow and production approaches.

3.2.2 Case studies

Similarly, case studies regarding application of lean health care vary from wide range of different classes and categories. Brandao de Souza (2009) distinguished four main categories: *Manufacturing-like, Managerial & Support, Patient Flow and Organisational.*

Manufacturing-like. In these cases, lean concepts are applied to flow of materials within specific units inside the healthcare facility, as pharmacy or radiology. The main feature of these units is their analogy, in terms of functioning, with a general production plant: even though they belong to a healthcare environment, the application of lean principles is similar to the one for production cases.

Managerial & Support. The main issue of these cases is the information flow within the organisation, as management of IT or administrative departments.

Patient Flow. This category includes most works based on application of lean in healthcare context. The main aim is improving flow of patients within the single unit or the entire healthcare facility. of course, it is important to consider that patient flow cannot be considered as flow of raw materials in production cases; it is crucial to ensure an elevated level of patient care and quality of service provided.

Organisational. In these cases, the organisational perspective of the implementation is taken into consideration, highlighting the relevance of designing a strategic and educational plan.

3.3 Application of Lean Healthcare

In the following sections, some applications of lean concepts introduced in healthcare context have been reported, to understand the several ways of application, different results deriving, and strain needed for the implementation.

3.3.1 Virginia Mason Medical Center

Virginia Mason Medical Center in Seattle is an integrated system of assistance, including nearly 340 beds and more than 5000 employees. In 2002, as consequence of economic crisis, the top management of the center decided to perform a radical change of the organizational structure: starting from the idea that healthcare context is similar to the Japanese car manufacturing industry (in terms of quality, safety, customer satisfaction, staff satisfaction and cost-effectiveness), Virginia Mason Medical Center created its own Virginia Mason Production System (VMPS), based on the TPS model. The VMPS can be represented graphically, as the TPS-House, in a triangular shape, on the top it is positioned the patient, supported by four different pillars: people (referred in terms of personnel), quality, service and innovation. The belief is a *patient-centered* vision, whose satisfaction should be considered the main goal of the company and system design should be modelled around patients' needs.

An example of translation of TPS concept in the Virginia Mason Medical Center was the introduction of *stopping the line* principle, under the name of *Patient Safety Alert System*, according to which every worker of the production line has the duty and the right stop production if an error is identified or even suspected. The basic idea is that errors are unavoidable, but if they are discovered in the early phases of the process they can be corrected, thus producing at the end a product with zero errors. At Virginia Mason Center, the Safety Alert System became part of a culture: from 3 notices of error per month of 2002, the number increased up to 17 per month in 2004. The person suspecting any possible mistake is in charged to contact patient's safety department and situation is immediately analysed; as such a reduction of more than 74% was obtained in liability claims from 2005 to 2015. Through the introduction of lean philosophy, the Virginia Mason Medical Center increased its productivity, reducing costs for more than $ 3 million and savings $ 6 million, avoiding the construction of new operating rooms, which as consequence of the lean management were unnecessary. The principle of continuous improvement for processes aimed at eliminating wastes, requiring less staff and less re-work and thus improve the quality of the services offered. Moreover, the application reduced incidences of ventilator-associated pneumonia from 34 cases with 5 deaths in 2002 to 4 cases with 1 death in 2004, saving the organisation over a half-million dollars (Spear, 2005).

3.3.2 ThedaCare

ThedaCare is a complex agglomeration of 4 hospitals, a residence for elders, more than 20 clinics and different centers for mental diseased or addictions located in Wisconsin, USA. Their relationship with lean management began in February 2004, when they attempt to introduce some of the lean principles in management of interactions with patients and in the internal organisation. Considering the first point, they analyse some operations (such as scheduling an appointment or receiving a diagnosis) which, if promptly executed, are perceived by patient as quality indicators; the aim was the identification of operations that impact most from patients' perspective. In addition, they listed also main possible negative events, that may affect patients' satisfaction, as for instance time needed for an authorisation before undergoing clinical treatment, waiting times for bureaucratic procedures or having to repeat tests or clinical examinations prior to determined operations. With respect to the second point, they focused on critical activities, and, through of the relevant value stream maps, sources of wastes have been identified and eliminated to encourage the rapid improvement of the process. Through the implementation of lean procedures, ThedaCare was able to increase productivity of different departments of more than 30%, resulting an increase of 24% of gross margins and a reduction of 44% of processing times.

3.3.3 Denver Health's Eastside Clinic

Eastside Clinic in Denver is a specialised Clinic offering a wide variety of services including prenatal and postpartum care, pediatric and teen primary care. It was observed that a large portion of mothers were voluntary missing postpartum visits because of transportation barriers and long appointment wait times experienced.

Main stakeholders focused on lean principles to identify which improvements to implement in order to encourage mothers' postpartum and preventive care. The initiative, started in 2015, included a series of Rapid Improvement Events, in which it was suggested to link babies' check-ups with the postpartum screenings for moms; in this way it would be more likely for mothers to perform post-partum visits while waiting for babies' check-ups. To achieve this, it was necessary to coordinate efforts and timing of women's and pediatric clinics, focusing especially on time spent by mothers' during the entire process and allocating staff in tracking multiple service lines, so that if a provider was behind schedule, staff reported it to patients, which could decide whether waiting or seeing another provider.

A time study of patients' path based on lean principles was conducted, starting from check-in. A long wait (estimated as more than 15 minutes to consult a provider) greatly reduced patient's overall satisfaction, irrespectively of quality of care provided. A color-coded system flagging on-time, delays or bottlenecks was used to quickly identify any possible source of delay in the entire process. Moreover, exam rooms were properly fitted, and logistics were mapped, so to avoid excessive movements and transfers of patients in and out of different rooms. The lean process ensured that the most important problems or issues were inspected from all perspectives, especially the ones of patients (for instance a common patient's perception was that they would have to spend half their day only for a 20-minute visit with a provider).

The results after the implementation of lean techniques showed an 85% of participation of mothers to postpartum visit, compared with less than 50% observed before. In terms of providers' rating, more than 80% of provider were rated 9 or 10 on a 10 scale rates. Monthly metrics reported between 80- 94 % of the pediatric patients were seen within 15 minutes of check-in, compared with previous 35%. From 2015 on, Denver Health has involved more than 2,000 of its employees in Lean improvements and in 2016 it was awarded with Peak Performance Award, rewarding organizations for the high overall performance excellence, achieved through a strong leadership and strategic planning, combined to improve the patient experience and higher quality care provided, through the use of Lean tools and a Lean Management System..

3.3.4 Ospedale Galliera di Genova

Regarding an Italian example, Galliera Hospital implemented a multi-year project to spread lean concepts within the company, starting from 2007 (P. G. Nicosia, F. Nicosia, 2008). The project, named G.E.N.O.V.A. (Galliera Empowerment by

New Organization and Value Analysis), attempted at redesigning facility based on the care pathway model.

The lean project team consisted of 20 interdepartmental members, including nurses, physicians and administrative of different units inside the hospital, the team then constructed the Value Stream Map of different processes, divided for diseases. In order to successfully implement lean concepts, multiple education programs were compulsory introduced for two thirds of the company, over the five years period of analysis. One of the objects of lean project consists of improvement of the operating rooms, through the creation of a new block of Recovery Room and introduction of new rules for positioning of patients in the unit. Another application of lean concept involved visual management tools, through the use a board, in the intensive care unit, aimed at monitoring the condition of hospitalized patients and the evolution of treatments. For each of the patients, there are two horizontal lines reporting the planned treatment and the treatment actually given. On the board, days spent in hospital, main events or relevant information, eventual transfer to in-patient ward for each patient.

By the end of 2009, Galliera Hospital achieved:

- 47% increase in Day Hospital activities;
- 70% decrease of extra work for nurses;
- reduction of 40% of space occupied for operating blocks;
- more than 150 members of the hospital educated on lean principles;
- 19% increase productivity and increase of 12% bed turns in intensive care units.

Altogether the hospital registered a cost saving of € 3.5 million from 2007.

Chapter 4 Simulation Modelling

Recently, the application of lean thinking in healthcare has constantly increasing over last twenty years in response to rising demand caused by population growth, ageing and high expectations of service quality. However, there is still some reluctance in the adoption of lean, mainly because of limited examples of validations and implementations and lack of measurable evidences. However, the integration of simulation tools in lean principles enables healthcare organisations to improve quality of service provided without increasing costs and risks to either the organisation itself or to the patients. In fact, simulation, taking into consideration variability and evaluating *what-if scenario analysis*, allows before actual implementation —hence before any investment— to evaluate and determine the effects of lean improvements. Firstly, it is necessary to introduce general principles of simulation modelling, outlining main features and categories of simulation modelling; then, simulation modelling will be presented in the specific context of healthcare environment, focusing mainly on the utilisation of Discrete Event Simulation and Lean Thinking.

As defined by Banks et al. (2005, p. 3), simulation is the «*imitation of the operation of a real-world process or system over time*». In fact, simulation modelling indicates the creation of a simplified model or prototype, used to represent, evaluate and forecast a real system. It is a powerful tool, used in many different fields, not only technological, in case replication of the actual system is unfeasible and extremely challenging, without the use of computer processing power. The simplified model is the representation in mathematical terms of the processes happening in the real system, which allows its comprehension. The accuracy of the simulation depends on the level of simplification applied; the simpler the model will be, the lower will be the accuracy. In order to properly understand simulation modelling, it is necessary to provide some definitions, as reported by Banks et al.:

« A *system is defined as a group of objects that are joined tougher in some regular interaction or interdependence toward the accomplishment of some purpose. […] A system is often affected by changes occurring outside the system. Such changes are said to occur in the system environment. In modelling systems,* *it is necessary to decide on the boundary between the system and its environment. This decision may depend on the purpose of the study. […] In order to understand and analyse a system, a number of terms needed to be defined. An entity is an object of interest in the system. An attribute is a property of an entity. An activity represents a time period of a specified length. […] The state of a system is defined to be that collection of variables necessary to describe the system at any time, relative to the objective of the study. An event is defined as an instantaneous occurrence that might change the state of the system. The term endogenous is used to describe activities and events occurring within a system, and the term exogenous is used to describe activities and events in the environment that affect the system.* » (Banks ,J. et al, 2005).

Depending on the system, it is possible to have different categories.

*Discrete-Event vs Continuous-Event***:** in the former, the state variable values change only at some discrete points in time, called event times; instead in the latter state variables change continuously over time.

Stochastic vs. Deterministic Systems: stochastic systems are characterized by randomness and their results are random variables, whereas in deterministic systems future states are not affected by randomness.

Static vs. Dynamic Simulation: in static simulation models, time is not a determinant; instead in dynamic models, output is dependent from time.

Modelling process can be described in three steps: in the first phase, the real problem that model wants to represent must be studied and understood. Only after having fully analysed the real system, it is possible to continue with second step, in which the model is created. In this step, it is necessary to collect data of the real system, to consider simplifications required for building the model. Then, a proper technique must be used to solve the model and results must be revised and verified, with adequate interpretations. Finally, results obtained from the model must be adapted to the real systems.

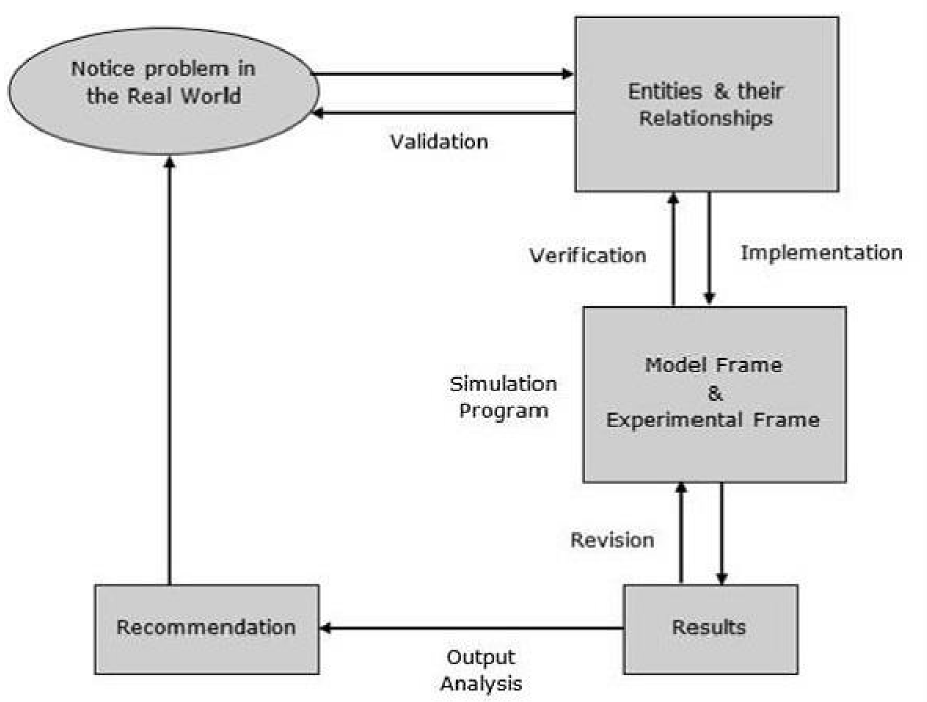


Figure 15 Main Steps of Modelling Process (Source: https://www.tutorialspoint.com /modelling_and_simulation/modelling_and_simulation_concepts_classification.htm)

Simulation models can be divided in the following categories: Monte Carlo simulation, System Dynamics, Agent-Based simulation and Discrete-Event simulation; it is possible to consider also an additional category, in which are stochastic modelling methods are included, as Markov model and Queuing model.

Monte Carlo Simulation. Generally used for risk analysis, it is a mathematical technique that generates random variables for modelling risk or uncertainty of a certain system; those variables (also called input) are based on probability distributions. Different iterations or simulations are run for generating paths and the outcome is obtained by using suitable numerical computations. Depending on the uncertainty, a Monte Carlo simulation could involve thousands of runs and calculations before it is complete. Monte Carlo simulations is often used to evaluate the expected impact of policy changes and risks in decision process, when considering healthcare environment (Mielczarek, 2016). The advantage of a Monte Carlo-based simulation is that it provides responsiveness, reporting possible outcomes and showing the impact of variables, allows a better control of threats and risks of the system; moreover, it can be applied and implemented to any possible industry or area.

Agent-based modelling (ABM). ABM is a computational approach in which agents with a specified set of characteristics interact with each other and with their environment according to predefined rules, derived from the real system (Tracy M. ,Cerdá M. and Keyes K.M., 2018). Agents can be either active (as patients, doctors or generic personnel) or passive (as infrastructure) and they are able to learn based on experiences, interactions and external factors. The difference in ABM is in the representation based on agents: simulated individuals make their decisions, including their personal characteristics and the social and physical environment.

System dynamics. System dynamics is an abstract type of simulation model, since does not require specific details about the system; it has been used to model complex systems, as the healthcare system. In this approach, a system may be represented as a causal loop diagram, which is a map of the system and its components, including the interactions among those (Sterman, 2000) .The causal loop allows to understand system's structure and behaviour, and obtain a qualitative analysis; in order to have also a quantitative perspective of the system, it is possible to introduce stocks and flows: a stock represents any dynamic entity moving through the system, which increases or decreases over time; a flow represents instead the way in which a stock changes. These models are particularly used to model high-level system behaviour in large populations (Luke, D.A. and Stamatakis, K.A., 2012).

Discrete-event simulation. In the DES, operations and activities of a system are modelled in a discrete sequence of events in time. Each event occurs at a particular instant in time, called transition phase; between two consecutive events, the system is unchanged.

Stochastic modelling: Markov and Queueing model. Markov Chains address decision on uncertainties in a continuous period of time. The increasing processing power of computers boosts the application of these models to healthcare facilities. In Markov models, individuals are associate to a specific state at any given time; when changing their conditions, individual shift from one state to another, during the transition phase, with a given transition probability. One disadvantage is the memory-less characteristics of Markov models, since it is not possible to keep data on what occurred on previous cycles (Markov Model [online], 2016). Queuing theory concerns the study of waiting lines in the analysis of systems that provides service to random demands. A basic queuing system consists of an arrival process (which describes how customers join the queue), the queue (in terms of behaviour of customers in the line, queueing discipline), the service process that customers are waiting, and departures process; all these processes are modelled through probability distributions.

4.1 Simulation Modelling Healthcare

In the thirty years, the healthcare system has been facing several challenges all over the world; similarly to manufacturing industry, critical issues as cost reduction and resource optimisation have been largely discussed and many solutions manufacturing-based proposed. Particularly, simulation modelling techniques have been adopted to test possible improvements and changes in a risk-free environment, to provide a realistic representation of the real system, to understand and learn about the system (Robinson, 2004).

Due to the large variety of benefits, the literature on simulation applied in healthcare is constantly increasing over the last few years, with evidences of first application in 1960s and 1970s (M.M. Gunal; M. Pidd, 2010). Many were related to specific types of simulation modelling techniques, to specific applications (diseases, units, departments or whole hospital), and for different application purposes. According to that systematic literature review, DES is the most adopted in healthcare, but it is possible to provide some examples also for other types.

An example of the application of Monte Carlo simulation is related to immunization services in developing countries, to determine the optimal size of a vial and the optimal reordering point level, to obtain the best trade-off between costs (as purchase, transportation and holding) and loss, due to deterioration (Dhamodharan, A. and Proano, R., 2012). Instead when considering System Dynamics models, they are particularly used to model high-level system behaviour in large populations (Luke, D.A. and Stamatakis, K.A., 2012). Since ABM is based on the interactions between different agents, those models are usually implemented in case of infectious disease epidemiology, where interactions between individuals are essential for the transmission and the behaviour of the system. (Badhama J.,Chattoe-Brown E.,Gilbert N.,Chalabid Z.,Kee F. and Huntera R.F., 2018). Markov models consider the patients in a discrete state of health, and the events represent the transition from one state to another. These may be used for economic evaluation in health care considering the evaluation of costs and clinical outcomes, especially for evaluation of chronic diseases (Sato, R. C. and Zouain, D. M., 2000). In healthcare environment, the queuing models are generally used to estimate the waiting times (especially in the Emergency Department) and utilisations, to design the arrival process of patients and to analyse the appointment scheme used in the facility. (Fomundam, 2007)

4.1.1 Discrete Event Simulation in Healthcare

Discrete event simulation (DES) is the preferred modelling technique when considering healthcare problems, hence it will be analysed more in detail.
In principle, it is used to model real-world systems as a sequence of events, since in DES dynamic entities (patients) are modelled over time and in their interaction with system's resources; hence, every risk, activity or process is related to patients, which determine most of the unpredictability of healthcare systems (Mielczarek, 2016), providing a patient-centred representation.
In DES patients' attributes and their actions in the system (as arrival, time required for specific operation) are determined using probability distributions (Montgomery, J. B. and Davis, K., 2013). For this reason, DES is strongly applied when considering the optimization and analysis of patient flow (arrival processes, length of stay), in the allocation of assets, resources and locations and lastly in the so-called "what-if" scenario analysis. Because of the extremely high use of this technique, it will be deepened later, discussing different categories that have been identified and strengths and weaknesses of DES.
Discrete event simulation has already proven its capability and flexibility as a tool for the analysis and modelling of complex systems such as manufacturing systems or military operations, where the high level of uncertainty requires agility to reconfigure the system as the environment evolves. From the healthcare system perspective, patients or service providers (physicians, nurses and staff in general) are entities of the model; examples of attributes of entities may be age,

gender, other demographics, disease and medical records; this allows the characterization of each individual entity. Events include all possible situations that might happen during a simulation, as occurrence of a particular disease, admission, transfer or delay of medical treatments.

The growing popularity of DES in healthcare environment is reflected by the substantially and constantly increasing number of publications, particularly after 2010 (Zhang, 2018). As shown in the figure below, the number of publications, regarding DES application in healthcare systems, increased from around 5 papers annually published to almost 35 in 10 years (from 2006 to 2016).

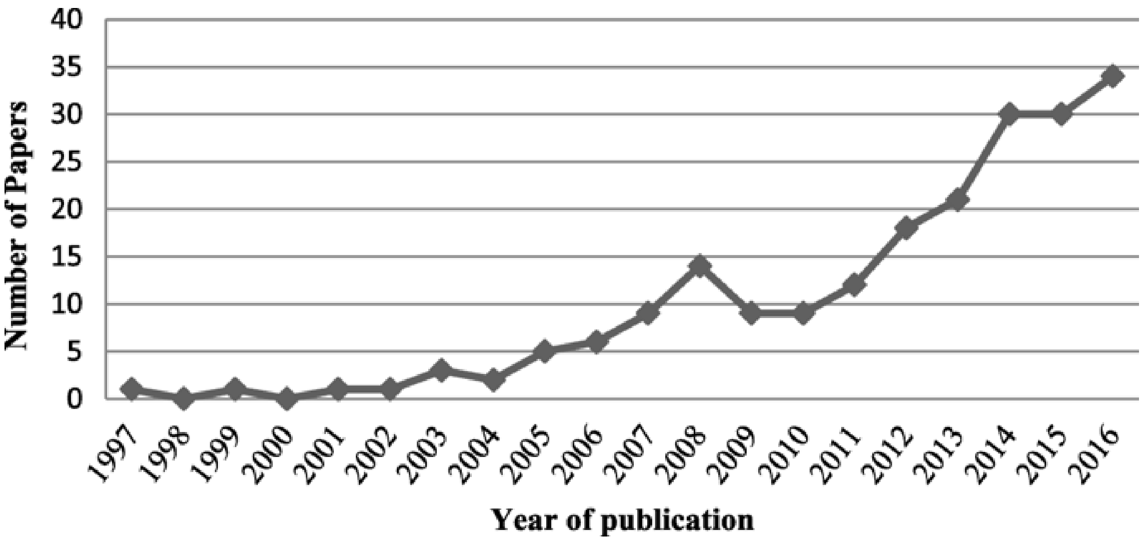


Figure 16 Number of DES Healthcare studies included in each year of publication (Source: https://rdcu.be/bYgtz).

Based on the review provided by Mielczarek and Uzialko-Mydlikowska (Mielczarek, B. & Uzialko-Mydlikowska, J. , 2010), DES models can be divided in four categories: *Disease progression modelling, Screening modelling, Health behaviour modelling* and *Health and care systems operation.*

Disease progression modelling consists of the application of DES to construct the course of disease. This is mainly applied to simulate different treatment decisions and their effects; an example is represented by the work of van Gestel et al. in which DES is used to conceptualized glaucoma (*i.e.* an ocular condition involving the irreversible loss of retinal nerve fibers) and its treatment choices made in clinical practice. The structure of the model adopted in this case has enabled the authors to distinguish relevant characteristics of each patient and of treatment strategies, which would have been impossible by adopting a Markov structure (van Gestel et al., 2010).

Screening modelling uses DES to examine people suffering of a given disease; particularly this type of modelling has been mostly applied to cancer screening and especially to breast cancer screening.

Health behaviour modelling has been already pointed out the complexity of the healthcare environment and one of the main causes is behaviour of different entities (patients and service providers), which are generally driven by psychological and not rational reasons. Hence, it is emerging the need to understand the behaviour of these entities in order to include also human factor in simulation models. The aim is the analysis a certain individual behaviour, over time and under different conditions, with the purpose of encouraging a healthier behaviour. The classic example of this category is smoking-behaviour modelling, through which individuals' life course of smoking behaviours, attempts to quit, and the cumulative impact on health and economic outcomes are modelled (Getsios D. et al., 2013). Each individual is assigned one of the possible solutions to quit smoking, which are monitored overtime. Based on each individual's smoking or abstinence patterns, the risk of developing diseases associated with smoking is determined with corresponding costs (Getsios D. et al., 2013).

Health and care systems operation is the most common category of application, regarding DES modelling, and it is meant to understand how the healthcare system operates. Generally, DES has been applied to specific single units (in particular Emergency Department is the most popular area for simulation modelling (M.M. Gunal; M. Pidd, 2010)), with some efforts of application on a more aggregate level (as whole hospital for example). From the literature and previous reviews, it has been possible to identify six main applications, consisting of *patient scheduling, resource allocation, capacity planning and management, staff scheduling, system diagnosis and evaluating the effects of operational* *changes or reconfigurations*; in order to understand the effective advantage in using DES, it is necessary to provide some examples of previous work. Under *patient scheduling, appointment and discharge scheduling* for both outpatient and inpatient care are taken into consideration. Great attention in this field is given to the surgical case assigned problem (SCAP), in which, according to a given criteria, patients must be assigned to different multifunctional operating room. Addis et al. (Addis et. al, 2016) so-called rolling horizon approach for the patient selection and assignment. They calculate the schedule for several weeks given the waiting list, leaving free time for incoming patients. During the first week, if unpredictable extensions of surgeries occur, they cancelled some surgeries and rescheduled others in the following weeks. Also, new arrivals are considered in the calculation of the final schedule. The midterm solution is rescheduled, limiting the number of variations from the previously computed plan.

Similarly, also *staff scheduling* is one of the main problems addressed with DES. Every scheduling problem is different because of the constraints in personnel available and legal framework in which the healthcare facility operates. In Centeno et al. the simulation is combined with integer linear programming to help emergency room management to staff their departments without incurring in over-cost (Centeno et al., 2003). Intensive care units (ICU) bed sizing and management is one of the main implementations when considering *capacity planning problem*. This is due to the criticality condition of ICU patients, which requires to be assisted with almost no waiting time. The number of the ICU beds has an impact on hospital performance: lack of the ICU beds may cause surgery cancellation, while an excess of ICU beds may cause a waste of resources. Zhecheng et al. (Zhecheng Zhu, Bee Hoon Hen and Kiok Liang Teow, 2012) applied DES model, in order to consider either emergency or elective cases. The ICU beds are assigned on first come first serve basis (FCFS, similar to the FIFO logic of production systems). Once all the ICU beds are occupied, the incoming emergency cases will be overflowed to other departments or diverted to other hospitals and the elective cases will be cancelled. The model was also used to test the what-if scenarios the healthcare service providers are interested in, which is another possible use of the DES, in terms of evaluation of future changes and configurations.

However, it is important to provide also some critical aspects of the application of DES deriving from literature. Firstly, as already mentioned, most of works are unit or department specifics, meaning that their focus is on finding a solution to problems arising in a specified part of the hospital. Therefore, it not possible to find a common sense: even though different works may focus on similar problems, this effort is rarely translated into the creation a generalizable theory. Moreover, as a result of the narrowness of problem, the level of simplification assumed may be too elevate; focusing on a specific department may lead in ignoring the complexity of the whole hospital, over-simplifying the entire picture (M.M. Gunal; M. Pidd, 2010). Secondly, most of the DES models are specific for a particular hospital, and they are never re-adapted to other cases; thus, there is an issue on the value and feasibility of reuse of DES model (Robinson, 2004).

4.1.2 Sim-Lean: using DES with Lean in Healthcare

After having introduced Lean and DES separately, it is interesting to see how these two concepts can be used jointly, providing a mutual benefit. In fact, they share similar values: improving the process or service delivered. A typical use of DES applied in a Lean context is the representation of a dynamic process or value stream map, to illustrate the as-is and to-be situations. However, applications of DES to more general lean principles can be found in the literature; Shannon et al. (2010) present a DES model that allows users to evaluate the impact of alternative strategies, such as batch sizing, workstation processing time and rework time, or in a more general perspective, DES has been used for determining effects and outcomes of different lean suggestions before their actual implementation (Young et. al , 2004).

DES and Lean are largely adopted independently. Robinson et al. (2012) discussed the complementarity of Lean and DES either from a theoretical and empirical perspective.

From a theoretical point of view, they showed how key concepts of *Mura, Muda* and *Muri*, deriving from Lean philosophy can be re-arranged in terms of DES. as mentioned in the *Chapter 2*, *Mura* refers to variability in the process as source of inefficiency; in this regard, DES can be used to model process variability, with main purpose of achieving demand smoothing. As reported in ***Table 3***, DES can be applied differently in order to reduce each of the seven wastes (*Muda*) defined by Ohno. For instance, it can be applied as modelling queues tool, for reducing the level of inventory.

Table 3 The role of DES in reducing waste (Source: Robinson, S., Radnor, Z., Burgess, N., and Worthington, C., 2012)

Ohno's original wastes	Role of DES
1. Transportation: moving products that are not actually required to perform the processing	Modelling the process flow and measuring transportation times
2. Inventory: all components, work in process and finished product not being processed	Modelling queues (inventory)
3. Motion: people or equipment moving or walking more than is required to perform the processing	Modelling the interconnection between resources (people and equipment) and the process
4. Waiting (Delay): waiting for the next production step	Modelling queues that evolve as a result of variability in interconnected processes
5. Overproduction: production ahead of demand	Modelling the interconnection between variability in demand and variability in production
6. Over- or inappropriate processing: resulting from poor tool or product design creating activity	Modelling the process flow and measuring utilisation of resources and processes
7. Defects: the effort involved in inspecting for and fixing defects	Modelling of variability in defect incidence and detection, and its impact (interconnection) on the process flow

Similarly, DES can be used for determining optimal resource allocation, especially in case of human resources allocation. Modelling personnel contribution within a process allows a deeply understanding of their security and comfort, which is exactly what *Muri* focuses on: reducing the stress on personnel.

Once understood that from a theoretical perspective DES and Lean can be complementary methodologies, Robinson et al. (2012) reported empirical evidences of complementarity, through a survey conducted in two English hospitals. The results highlighted that this methodological combination is perceived to be effective in two different categories: as mapping of processes, using DES to provide a software-based value stream map, and as a *what-if* experimenter, to test different scenarios and changes.

Chapter 5 Case Study: Cardiology of Maria Vittoria Hospital of Turin

Founded in 1885 by doctor Giuseppe Berruti, the Hospital Maria Vittoria takes its name from princess Maria Vittoria and from its foundation it is reference hospital for the maternity and childcare department. The Hospital is part of the services managed by the former ASL TO2, now ASL "City of Turin" from January 2017, counting a pool of nearly 230.000 citizens; in practice, it is reference hospital for North-West district of the city, serving nearly 130.000 citizens. It includes 301 beds of ordinary hospitalization divided in more than 30 different departments; moreover, as one of the five general hospitals of reference for the metropolitan area of Turin, it is the headquarters of DEA - department of emergency and acceptance: it is a crucial part of the Hospital, due to the fact that it is most crowded emergency department of city, with 83.662 visits in 2019[5].

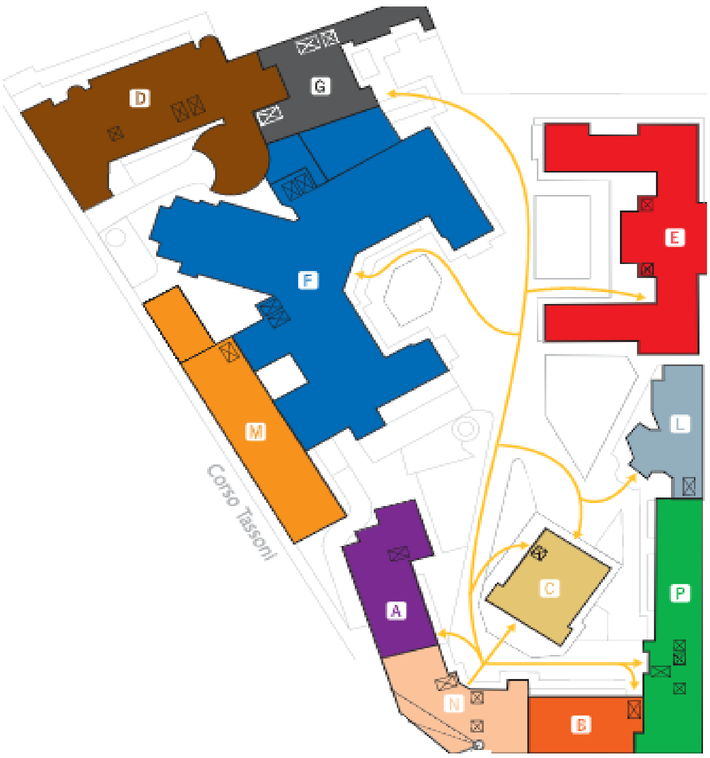


Figure 17 Maria Vittoria Hospital Map (Source: https://docplayer.it/2935024-)

[5] Data reported by Chief Medical Officer of Maria Vittoria Hospital

The object of this work is the application of lean principles to the Cardiac Department of Maria Vittoria Hospital of Turin. As result of different challenges faced by the unit, the department Chief, Dr. Massimo Giammaria, reported his willingness to apply engineering concepts to their operations, to increase efficiency and efficacy of service provided. The methodology applied in this work is aimed at the identification of all possible areas of improvements and suggestions for future developments and modifications; in particular entire Department will be presented for a general overview, then a preliminary data analysis will be done for identifying different processes performed within the department and select the scope of action, that will be mapped in detail and will be object of improvements; this will be analysed in detail and solutions to critical aspects will be proposed. Specifically, the DMAIC Six Sigma framework enables the identification of critical points and possible strategies to facilitate and improve patients flow.

5.1 System Description: Cardiology Department

The first step is the definition of the system that will be analysed; this essentially implies the description of the Cardiology Department of the Hospital. The Department, located sector D of the hospital, includes a Cath Lab, a Electro Physiology Lab, an Intensive Care Unit, a Cardiology Ward and a Cardiology Surgery, providing a total of 28 beds, respectively 18 for normal hospitalisation in the ward, 2 for day hospital or day surgery procedures, 8 in the intensive care unit; in addition, there are four beds, two for each of the different labs, dedicated to temporary hospitalisation for patients who undergone invasive lab interventions and are waiting for normal or intensive care bed. The different sections are distributed on three different floors. Starting from the first floor, where the ward is placed, to the -1 floor, where it is possible to find Cath Lab, there is an increase of severity and care needed by patients, which therefore can be translated into an increasing need of nurses and physicians.

In general, cardiology wards can be divided in three main levels, depending on their technical and organisational complexity.

First level. A cardiology ward belonging to the first level performs all the activity and functions of ordinary hospitalization and intensive care assistance;

they include cardiac emergency, assistance in in-patient and outpatient cardiological diagnostics (non-invasive instruments), long-term management of high-risk heart disease (secondary prevention), chronic disease management in collaboration with territorial structures, therapeutic education and possible rehabilitation post-acute (continuity of care).

Second level. In this case, cardiology is characterized by the presence of the laboratory of interventional cardiology, which is able to meet all invasive therapy needs of reference territory. In addition to the functions exercised by the first level, the second level includes treatment of cardiopathic with special diagnostic/care needs, cardiac catheterisation procedures and contrasting findings.

Third level. In addition to the second level, a third level cardiology includes a cardiosurgical structure in the site. Moreover, third level cardiology are obliged to meet all therapeutic needs unmet by other levels and related to cardiosurgical procedures and hybrid procedures.

The cardiology ward of Hospital is a second level cardiology, since it includes two labs of interventional cardiology, but it does not present a cardiosurgical room, as for instance the Molinette Hospital. Different cardiology departments of Turin constitute a network, organised on interaction and functional complementarity between individual structures belonging to the network, regardless of their physical and administrative location. The network allows a greater focus on the entire care pathway, rather than on the single intervention. The adoption of network ensures continuity of care, improving the integration between healthcare facilities and population; besides, it avoids duplication of performances for a single patient and ensures a common shared knowledge of personnel of different hospitals. The network is based on the *Hub & Spoke* model, expressing a dynamic idea of care related to the degree of complexity; therefore, the relevant services are organized centering activities and operations of high complexity in Reference Centers (*Hubs*) and identifying linked Centers (*Spoke*), which must select and send patients to reference centers for the aforementioned operations and take in charge again patients after the execution of treatment. The Maria Vittoria hospital Cardiology is a Hub Center, reference point for all the other cardiology wards not disposing of specific Labs for invasive procedures (Struttura e organizzazione funzionale della Cardiologia, 2003).

In order to have a clear understanding of the Cardiology Ward, it is necessary to first define main features of different sections constituting the ward.

5.1.1 Intensive Care Unit

The Intensive Care Unit (*Unità di Terapia Intensiva Cardiologica UTIC*) is the unit ward dedicated to patient affected by acute coronary syndromes and all cardiovascular emergencies, requiring a constant vital signs monitoring. It is available 24/7. According to standard provisions, each UTIC should have as immediate access to a Cath laboratory, an interventional arrhythmic laboratory and a cardiosurgical center, if those are present in the facility. In the hospital the UTIC is located at the ground floor of the facility, nearby the Cardiology Surgery and the Electro Physiology Lab. It consists of a single room, in which there are eight beds reserved for more acute patients, constantly monitored at sight from highly skilled nurses and doctors; generally staff-to-patient ratio is much higher in a UTIC rather than a generic unit, in this case, 2 or 3 nurses and a doctor on duty are always available in the central station of the unit, equipped with 4 working stations with computers to access and update patients' information on hospital's information and managerial systems. In UTIC, each bed is equipped with relatively recent bed head, including eight power connections and lights for each bed. On the wall for patient, it is possible to find a monitor, which records and investigates each beat of patients' heart rhythm, and alerts the staff immediately if serious arrhythmias occur, ventilation devices, eight infusion pumps for dosage of specific drugs and potential equipment deriving from Cath laboratory. Considering staff, in the UTIC Units there are three nurses shift, from 7:00 to 14:42, from 14:32 to 22:42 and from 22:35 to 7:10, with two charge nurse per shift; nurses are assisted by one CNA Certified Nursing Assistant (in Italian *OSS Operatore Socio Sanitario*) in the morning and one in the afternoon. With respect instead to doctors, there is always one doctor available for UTIC units, rotating with the rest of doctors of the department, for operations between 8:00 and 17:00; whereas in the afternoon (14:00-21:00) and during the night (21:00-9:00) there is one doctor per shift, in charge of monitoring patients in both UTIC and Cardiology

Ward. Moreover, every morning there is a one-hour meeting with 4 to 5 doctors, head nurse, one nurse and the chief doctor to evaluate the health conditions of UTIC patients and possible transfers to Cardiology Ward.

5.1.2 Cardiology Ward

The Cardiology Ward, located at first floor of the hospital, consists of 10 rooms, with two beds and a private bathroom per each room. These room are dedicated to inpatient or post-surgical admissions, for not severe or not urgent patients; two of the total 20 beds in the ward are reserved for day hospital/day surgery operations. Differently from the UTIC previously described, bed heads of each bed are not so recent, since in this case either power connections or gas tubes (oxygen, vacuum for aspirations and compressed air) are not included on the bed head, but they are instead on the wall. Inside the cardiology ward there is a computer workstation for personnel, a monitoring room, including 20 monitor reporting heart rhythm of each of patient hospitalised, a deposit with an electrocardiograph, an echo and some AEDs, a recreation room, a room for organisation of meals and the Director's office. In terms of personnel, the Cardiology Ward has the same staff composition of UTIC unit either in terms of nurses and their shift, or in terms of doctors and their shift; the only difference is on the number of Certified Nursing Assistant, since in the Cardiology Ward there are two CNA in the morning and 1-2 in the afternoon.

5.1.3 Cariology Surgery

On the same floor of UTIC it is possible to find also the surgery dedicated to specific cardiac diseases. The surgery is open from 8:00 to 16:00, even if most of the times it is opened for public before 8:00 and after 16:00, and it consists of a series of different rooms, each dedicated to a specific examination. More in detail, there are:

- Two echocardiography rooms, equipped of electrocardiograph, defibrillator, infusion pumps for specific drugs, a dedicated sterilizing probes machine and machinery for echocardiography;

- A room for pacemakers check, in which besides electrocardiograph and defibrillator, there are also computers of each pacemaker producer companies;
- A room for generic cardiac visit;
- A room for Stress Tests and Holter, in which there is an electrocardiograph and treadmill for help diagnose and evaluate heart problems such as ischemic heart disease, heart valve disease, or heart failure.

In the surgery it is also a desk for patient registration, in which a secretary enters patient's information within hospital's information system and makes patients wait in the waiting room. Concerning personnel, there are four to five physicians, one for every room, depending on personnel availability and scheduled visits, an administrative (secretary) and 4 nurses, respectively one assisting echocardiography rooms, one for stress tests and Holter and remaining two rotating on all rooms.

5.1.4 Cath Lab

The Cath Lab is placed at lower level (floor -1) with respect to the other parts of the Cardiology. It is important to mention that the hospital is modifying the Cardiology, through the construction of Electro Physiology Lab opposite to the Cath Lab. The Cath Lab consists of a hemodynamic-angiographic room, with sufficient space for necessary equipment and for easy movement of the personnel and any resuscitation manoeuvres in case of need. The lab is equipped with equipment necessary for the operation, as a cardio-angiographer, medicines and instruments for cardiorespiratory resuscitation, including defibrillator and temporary pacemaker, oxygen dispenser, infusion pumps, pulmonary ventilator; various tools needed for angioplasty and implantation intravascular stent. Besides the operation room there is also a control room, in which technicians and physicians monitor:

- The patient undergoing procedure, through the "polygraph", which allows continuous supervising and registering of the ECG, with at least two intravascular pressures and/or intracardiac catheters, pressure transducers, and pulsis-oxymetry. Those signals are also visible on a monitor in the operation room during the procedure;

- The invasive advanced imaging technology for coronary;
- The X-ray equipment;
- The heart rhythm of four patient that can temporary be in the Lab;
- A monitor for updating information on hospital management system.

There are also other rooms for the preparation and storage of material, including documentation, for the washing and dressing of personnel, separated from the hemodynamic room, for sanitisation, cleaning, disinfection and sterilization of medical devices; this space is extremely important for successful operations, since it impacts on patient and staff security and safety.

In the lab are always available 2 cardiologists specialized in hemodynamic, with the third generally available in the Cardiology Ward; nurses associated to Cath or Electro-Physiology Lab are divided in two shifts (8:00-15:42 and 9:30-17:00) with 3 nurses per shift that rotates on both Cath and Electro Physiology Labs, similarly there is also one CNA per shift, following the same time schedules of Nurses; moreover, the lab is normally opened from 8:00 to 17:00,but there is always a call team consisting of nurses, certified assistant nurses, and radiologic technologists and surgeons available twenty-four hours a day for emergencies. In terms of radiologic technologists, there are generally two Tech per shift, but in this case their scheduling is managed by Radiology Department.

5.1.5 Electro Physiology Lab

Currently, the Electro Physiology lab is located in the UTIC section of the Cardiology on the ground floor. The Lab contains high-technology equipment used to monitor and map the electrical systems of the heart as well as treat heart rhythm disorders (arrhythmias). The three main procedures conducted in this lab include cardiac mapping, cardiac ablation and insertion and implantation of devices (i.e. pacemaker or implantable cardioverter defibrillator). In case of Electro Physiology Lab, the personnel are scheduled in the same way of the Cath Lab, with the only difference that in this case doctors are specialized on electro-physiology procedures.

5.2 Preliminary Data Analysis

In order to understand and evaluate which is the most likely area of improvement, it is necessary to collect all data and information related to the aforementioned system; the entire process of data analysis is reported in the ***Attachment 1*** *Flowchart Data Analysis Process*. To improve the services provided by Cardiology Department, it was necessary to deeply understand different activities and processes carried out within the Department. Since Cardiology is composed by five different sections and provides various operations and treatments for different types of patients, it was necessary to enact some simplifications of the entire process.

Firstly, we focused on ordinary patients, *inpatients*, namely patients which are admitted in the cardiology ward under an ordinary recovery, neglecting day hospital/day surgery patients and patients entering the department for follow-up, stress tests and all other operations done in the Cardiac Surgery; a different treatment will be considered for patients coming from Spoke Hospitals, other departments or other private/public facilities, which will be discussed later on. The choice of analysis inpatients is mainly due to the fact that these require more resources in terms of personnel and equipment, and therefore their length of stay within the hospital is higher, which consequently increases the cost for their hospitalisation.

In order to categorize different patients entering the Department the first distinction was made based on the operations and treatments required by each patient. Patients, in fact, can be admitted to the Cardiology Ward if they require Hemodynamic procedures, Electro Physiology procedures or other procedures. Briefly, while Hemodynamic procedures focuses on diseases related to blood flow, mainly ischemic heart disease, Electro Physiology is a slightly different cardiology branch, focusing of the study and treatment of all diseased related to electric flow through the heart; all other heart pathologies, not included in fluid dynamics of blood or electric flow are referred to other procedures.

The analysis conducted in this work will be based on data contained in the *SDO Scheda di Dimissione Ospedaliera*, which is the documentation, either in printed form or electronic form, filled in at the end of the hospitalisation, used for collecting information on all hospitalisation in public and private hospitals throughout the Italian country. An example of the SDO already anonymized (data referring to identification of medical report and patient have been omitted) is reported in the ***Figure 18***.

Erogatore	Data prenot	Data ricover	Data dimissio	DRG	DGN princ.	DGN sec. 1	DGN sec. 2	DGN sec. 3	DGN sec. 4
0801 - Cardi	-	01/01/2018	11/01/2018	124 [M] - Mal	785.51 - Sho	427.32 - Flut	428.1 - Insuf	427.1 - Tach	426.3 - Altro

DGN sec. 5	Int. princ.	Int. sec. 1	Int. sec. 2	Int. sec. 3	Int. sec. 4	Int. sec. 5	Dimessi	GiornateA	Valori (€)
491.21 - Bro	88.56 - Arter	89.61 - Monit	89.54 - Monit	99.61 - Card	87.44 - Radio	88.72 - Diagr	1	10	3392

Figure 18 SDO Details

The SDO contains all information concerning patient records (including age, sex, residence, which are not reported in the ***Figure 18*** above because of privacy reasons), characteristics of hospitalization (as date of booking, admission and discharge, days of hospitalisation and facility of hospitalisation), clinical characteristics (as primary diagnosis, concurrent diagnosis, diagnostic or therapeutic procedures) and the *Diagnosis Related Group* code. The latter parameter is computed by a software (*DRG-grouper*) which depending primarily on the primary diagnosis and the number of days of hospitalisation, followed by main diagnostic or therapeutic procedures conducted and some of patient personal information, assign to each recovery a given DRG code and its correspondent monetary amount, which should be given to each hospital as *revenue* for that specific recovery. The *Diagnosis Related Group* is in fact a system for classifying all patients discharged from a hospital (admitted under ordinary or day hospital) in homogeneous groups for absorption of committed resources.

With respect to primary diagnosis and main diagnostic or therapeutic procedures, it will be adopted the definition provided by the Italian Ministry of Health, *Ministero della Salute*. The SDO contains six diagnostic codes from ICD-9-CM classification, of which one is labelled with primary diagnosis and the others secondary or concurrent diagnosis, which contribute to a more complete clinical picture. In general, the identification of main diagnosis can be made in two different ways: the first one is through a pure clinical criteria, establishing as the main diagnosis the disease that caused the hospitalization; the second one instead is based on an economic perspective, according to which the main diagnosis is the disease requiring the higher consumption of resources during the hospitalization and which does not necessarily correspond to the clinical cause of hospitalization. This second approach is now currently used in Italy. Similarly, there are also six codes relate to processes, again reported using the ICD-9-CM classification. Of these one is defined as main intervention, while the others are named secondary interventions. In this case, the identification of the main intervention is based univocally on processes performed during the hospitalisation requiring the greatest consumption of resources.

Data provided by Department Chief, Dr. Massimo Giammaria, refer exclusively to 2018-2019 ordinary recovery—admissions from 01/01/2018 and discharges up to 31/12/2019— because before 2018 there was a different management and in turns a different codification of pathologies detected and examinations done within department and recorded in the SDO, which would create bias in the data analysis; in addition, around 130 records (namely the 4.38%) were removed from the data set because their days of hospitalization were either zero or one day, which cannot be considered a valid value for ordinary recovery. The presence of these records can be explained either as an error in the drafting of SDO or simply patients arrived at the department by DEA but without any pathology or problem requiring interventions; in fact, analysing these data with Department personnel and in particular observing the list of interventions performed to these patients, it has been noticed that the majority of these patients arrive at the Emergency Department, complaining of chest pain, generally symptom of heart-related diseases, but that are immediately discharged (or discharged during the day) after a cardiological check-up or after a coronary arteriography, because no evidence of possible diseases has been found.

After having removed all non-relevant records from the dataset, admissions per quarter were analysed. Concerning the annual amount of service provided, in 2018 total admissions were 1398, meaning nearly 3,83 admissions per day, while in 2019 total admission was 1352 with a slightly lower average of 3,7 patient admissions per day; this data has been explained by Dr. Giammaria as reflection of different strategy implemented by the Department, consisting of less admissions for more complex operation, namely higher DRG, and more Day Hospital admissions for less complex procedure.

Additionally, only a limited part of admissions is deriving from elective patients, meaning patients whose intervention has been scheduled in advance and whose arrival is not random, but related to a precise appointment; in fact, taking into consideration the column of *Data di Prenotazione*, reporting the date in which a reservation for a treatment is made, only 28.6% of patients of department are elective (787 total patients with an appointment out of the total 2750 record in the dataset considered). The reason behind this relatively low percentage of elective patients is due to the fact that Cardiology Department is dedicated mainly to pathologies that must be urgently treated (as ischemic myocardial infarction, whose treatment cannot be performed in an elective way); however, most of elective patients are patients urgently hospitalised in past, who need to make an additional surgery in a determined time span. In fact, to each elective patient is assigned a different code, indicating the maximum time within which they must undergo the other intervention needed.

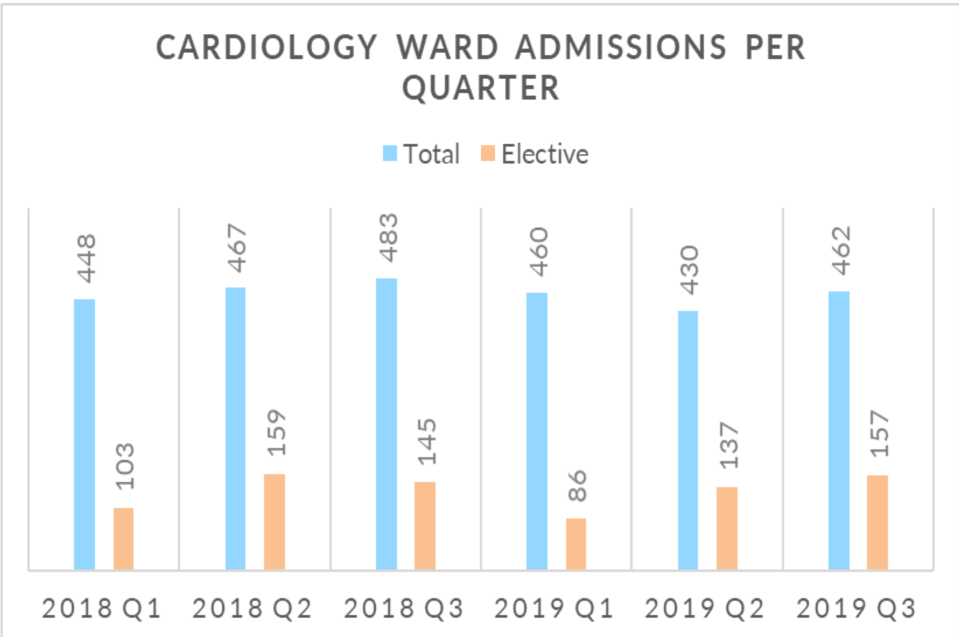


Figure 19 Cardiology Ward Total and Elective Admissions per Quarter

5.2.1 Catheterization Lab Analysis

It has been decided to focus on patients admitted to Cardiology Department for undertaking hemodynamic procedures, named Cardiac Catheterization procedure, which requires necessarily the utilisation of Cath Lab. The reasons behind this choice are related to importance of treatment of coronary artery diseases, whose improvements and developments increased average life expectancy over the years (V.A. Raghavan, 2010). Actually, cardiac catheterization is one of the most commonly invasive diagnostic procedures performed within the Cardiology Department and, additionally, because of specific equipment and specialists needed, costs associated with Cath Lab represent a significant part of costs incurred in the Department. It has been widely accepted (LeBlanc F, McGlauglin S, Freedman J, Sager R, Weissman M., 200) that Cath Lab is among the most substantial capital investments for hospitals, even though following the introduction of DRG classification it has become more difficult for hospitals to maximize its potential economic return. Moreover, as reported by OECD Report on Italy Country Health Profile 2019 (OECD, 2019), ischaemic heart disease and stroke are two leading cause of death in Italy, which of course increases the importance of effective improvements in the process of cardiac catheterisation procedure.

Once restricted the analysis to the Cath Lab, it was necessary to identify all patients within the dataset that were hospitalised for cardiac catheterization procedures; as first attempt, following directives of personnel, it has been decided to focus on coronary arteriography procedure, labelled with code 88. 56 according to ICD-9 procedure codes sets; in fact, almost all patients of a cardiology department perform a coronary arteriography, since it is a diagnostic tests necessary to identify the main pathology of the patient; after the coronary arteriography, patients can follow three different paths: first, they may have an operation related to cardiac catheterization procedure, second may have another procedure not related to cardiac catheterization or third, they may be dismissed because they do not present any disease. Then, in order to have a precise list of interventions requiring Cath Lab utilisation, two main codes were identified: code *00.66 - Percutaneous transluminal coronary angioplasty [PTCA]* or *35.96 - Percutaneous balloon valvuloplasty;* there is another possible Main Intervention code associated with this type of patients, which is the bypass intervention, but this specific treatment is a more invasive procedure then the ones reported above and it is not performed within the ward, reducing different flows of patients associated with Cardiac Catheterisation. These codes in fact are associated to the more general cardiac catheterisation procedures, while all other codes, which are associated to procedures related to Cath Lab, are always performed together with either an angioplasty or a valvuloplasty. As reported in the ***Figure 20*** slightly below the 68% of patients that have previously done a coronary arteriography continue in the Cath Lab for a PTCA procedure or in some rare cases for a percutaneous balloon valvuloplasty .

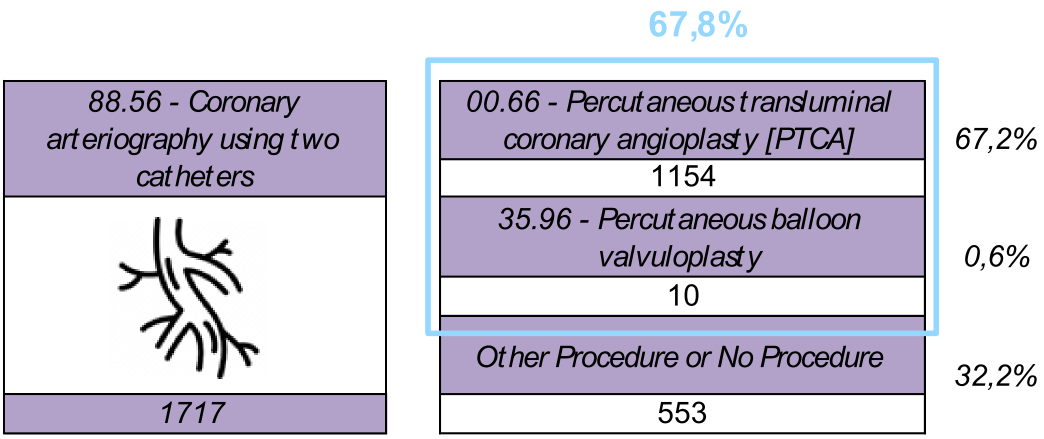


Figure 20 Percentage of 88.56 procedure code that performed also a cardiac catheterisation procedure

However, in order it has been noticed that filtering for code 88.56 and then for cardiac catheterisation procedure code does not include the entire number of patients associated with Cath Lab, which in turns undergone either an angioplasty or a valvuloplasty; to identify all patients associated with the Cath Lab, it is important to include also:

- patients whose main intervention code is either 00.66 or 35.96, but that did not perform coronary arteriography;
- patients whose main intervention code was not one of the two associated with the Lab, but that performed either intervention 00.66 or 35.96;
- patients that performed the 00.66 or 35.96 intervention several times, which of course, increase the frequency of the code inside the dataset.

To determine the effective number of patients whose treatment requires the Cath Lab utilisation, all patients’ record which present either the code 00.66 or 35.96, one or more times, in any of the Intervention columns were identified, independently if they also undergone coronary arteriography; considering these additional possibility another 1.1% of patients have been associated to Cath Lab. The results are shown in the ***Figure 21*** below reporting the percentage of those patients compared with the total patients admitted to the ward and number of patients associated with the Cath Lab per quarter. It was also highlighted the percentage of elective patient in each quarter, considering as elective patient the ones admitted in the precise quarter analysed and with a non-blank value for *Data di Prenotazione*. From this analysis it was possible to identify 1177 patients associated to Cath Lab, representing 43% of total patients admitted in the ward, with 19.2% of these elective (226 patients). In terms of interventions instead, almost all patients were associated to PTCA (1165 patients out of 1175) and only 12 records were reporting a Valvuloplasty intervention, as reported in ***Figure 21***.

Cath Lab Patients 2018		Cath Lab Patients 2019	
610		567	
99,0%	1,0%	98,9%	1,1%
PTCA	Valv.	PTCA	Valv.
604	6	561	6

Cath Lab Elective 2018		Cath Lab Elective 2019	
118		108	
97,5%	2,5%	100,0%	0,0%
PTCA	Valv.	PTCA	Valv.
115	3	108	0

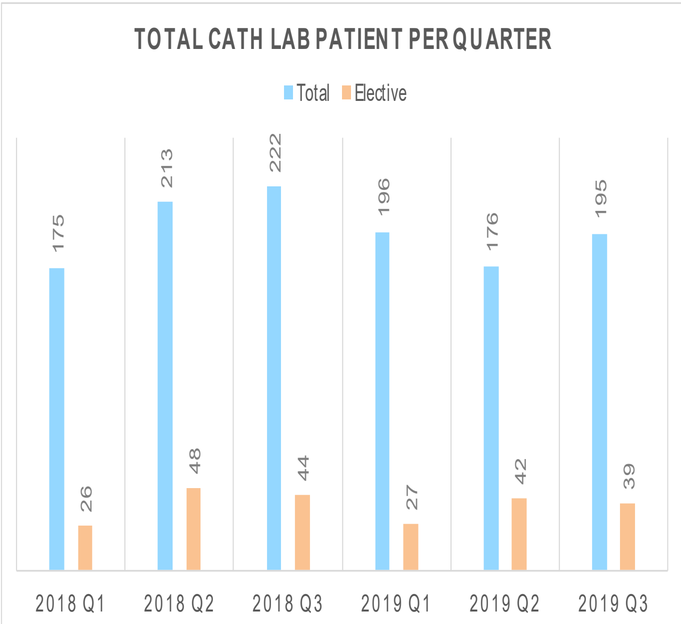


Figure 21 Total and Elective Cath Lab Admissions per Quarter

After having identified the complete flow of patients interacting with Cath Lab, the next step was understanding different flows and finding a categorisation of these patients; this analysis is not so trivial, since the hospital is a Hub Hospital and according to the definition previously explained, it receives patients also from different Spoke Hospitals or other public and private facilities, in addition to patients coming from the other departments internal to the hospital for performing cardiac catheterisation procedures. ***Figure 22*** outlines different flows of patients entering the Cath Lab, representing the predominant arrival methods with longer arrows; similarly, also main destinations were reported, summarizing principal paths departing from the Cath Lab.

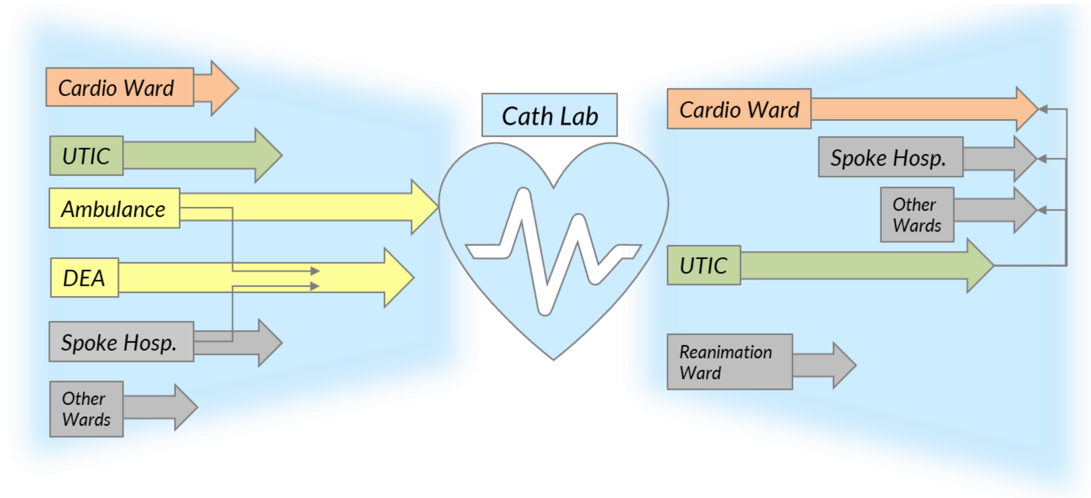


Figure 22 In-going and out-going Cardiac Catheterisation Lab flows.

It has been noticed that patients interacting with Cath Lab can be classified considering two main variables: the arrival mode and the clinical status; in case of arrival mode metric, patients can be *DEA*, *118*, *Elective* and *Other Arrival* Patients, whereas grouping for the clinical status, four main conditions will be considered, namely *Urgent*, *Less Urgent*, *Electives* and *No Problem* Patients.

Starting from the first classification, an estimation of the percentage of patients for each of the selected sources of arrival has been obtained through the ABACO software used by the Hospital to evaluate the performance of each department and the compliance with national indicators. As reported by ***Figure 23***, of the total Patients identified as Cath Lab patients, the majority arrives through the ambulance, after a call to emergency aid system 118; the second main source of arrival is spontaneous arrival at Emergency Department, whereas only with lower percentage there are elective and other arrivals. A plausible explanation can be found considering that either an angioplasty (00.66) or valvuloplasty (35.96) are procedures made after or in meantime of a myocardial infarction, whose clinical onset is unexpected and since it is associated with high mortality if not properly treated, it is necessary, as soon as any of the typical symptoms is identified, the call to the emergency aid system (118) or the arrival of the patient at a hospital.

00.66 Total 2018-2019			
1165			
118	*DEA*	*Elective*	*Other*
426	346	223	170
36,6%	*29,7%*	*19,1%*	*14,6%*

35.96 Total 2018-2019			
12			
118	*DEA*	*Elective*	*Other*
3	4	3	2
25,0%	*33,3%*	*25,0%*	*16,7%*

Total 2018-2019			
1177			
118	*DEA*	*Elective*	*Other*
429	350	226	172
36,8%	*30,0%*	*19,4%*	*14,8%*

Total 2018-2019		
951		
118	*DEA*	*Other*
429	350	172
45,1%	*36,8%*	*18,1%*

Figure 23 Cath Lab Patients divided per Arrival Type

Considering instead possible destination after the operation, it is necessary to take into consideration the percentage of success of the intervention; it has been estimated that only 3-4% of cardiac catheterisation procedure performed within the ward is not successful, with an additional 1-2% patients moved to the Reanimation Ward of the hospital in case of complications; in the general case, if the patients are urgent (but not critical) their destination is the intensive care unit (UTIC) or their original facility, if they arrived from other hospitals or other wards; in case instead of a general procedure for elective patients, if no complications happened, they are transported to the cardiac ward.

The second classification adopted for patients of the Department is based on the severity of clinical status of patients. As previously reported, patients can be labelled as *Urgent*, *Less Urgent*, *Elective* and *No Problem* Patients. Temporarily ignoring *Elective* and *No Problem* Patients, it is important to introduce the distinction between *Urgent* and *Less Urgent* Patients; in clinical terms a patient is classified as *Urgent* whether it has been confirmed a STEMI Diagnosis or N-STEMI Urgent Diagnosis; in this case the intervention needed must be done within a timeframe of 90 minutes from first medical contact (according to standard provisions); in case instead seriousness of patients is not so critical, clinically N-

STEMI Not Urgent or other Cardiac pathologies requiring Not Urgent Cardiac Catheterization procedures, patients can be considered as *Less Urgent*, which increases the time within which the procedure must be performed. Cardiologists of the ward listed some of the Main Diagnosis associated with Cath Lab patients, taking into consideration the severity of the diagnosis, as reported in the ***Table 4***.

Table 4 Clinical Disease associated with ICD-9 Diagnosis Code

Clinical Disease	Associated ICD-9-CM Diagnosis Codes
STEMI	Acute myocardial infarction: any Code **410.xy** with x≠7 and y≠2
N-STEMI	**410.71** - Subendo infarct, initial
Not-Stable Angina	**411.1** - Intermed coronary synd
Exertional Angina	**413.9** - Other and unspecified angina pectoris
Other myocardial infarction	Any Code **410.xy** with y=2

This classification enables having an estimation of Urgent and Less Urgent Patients; starting in fact from the dataset concerning Cath Lab patients, electives can be easily identified because they report a date in the *Data di Prenotazione column*, leading to select Urgent and Less Urgent patients as associated with no value in this column. Based on the classification of *Main Diagnosis,* Urgent Patients can be identified in case their *Main Diagnosis* code is either associated with STEMI or N-STEMI, or in case of 35.96 intervention code as associated with an acute heart failure or not chronic diseases, whereas the Less Urgent Patients can be identified as the ones reporting a code for *Not-Stable Angina, Exertional Angina or Other myocardial infarction.* However, since not all the records presented one of the previous mentioned code in the *Main Diagnosis* cell, to classify the remaining data the same operation was performed also on the *Secondary Diagnosis 1* values, leading to results in the following ***Figure 24***.

Urgent Patients	785	66,7%
Less Urgent Patients	166	14,1%
Total	1177	

Figure 24 Estimation of Urgent and Less Urgent patients

Once obtained an estimation of *Elective, Urgent* and *Less Urgent* Patients, it was necessary to derive also an approximated number of *No Problem* patients. In order to introduce also this category of patients and obtain a percentage of each of the types, it was considered the number of records, removed from the initial dataset, having Length of Stay equals to zero or one; using this assumption, the an initial percentage of No Problem patients is was estimated based on the entire population, leading to a 4.38%. It is important to remember that this is an oversimplification; some of the records removed was associated to errors in the drafting of the SDO or some of them nevertheless undergone the procedure in the Cath Lab. This value was multiplied for the number of Non-Elective Cath Lab Patients (951 records) derived from the dataset, in order to obtain a proxy of No Problem records associated with Cath Lab removed initially, which leads to 42 rounded patients record. Once determined this approximated value of No Problem Patients, it has been possible to estimate the percentage of the three types considered, as reported in the figure below.

Urgent Patients	785	*64,4%*
Elective	226	*18,5%*
Less Urgent Patients	166	*13,6%*
No Problem Patients	42	*3,4%*
Total	1219	

Figure 25 Estimation on percentage of Cath Lab Patients divided per clinical status

After having introduced the main classifications of patients, it was necessary to have a better understanding of the process executed inside the cardiology department, in case of cardiac catheterisation procedure. In general terms, patients can be considered as families products to be processed within a company: different families of products require a different set of operations and activities to be performed, in order to meet demand and satisfy customers' expectations; whereas, the different units and physical places in which patients are transferred can be considered as different workstations in which products are modified and processed. Three macro-categories of *"products"* were identified with assistance of ward personnel, namely *Urgent Patients*, *Elective Patients* and *Other Patients*. It is important to specify that Other Patients type has been introduced, since patients arriving from other facilities or other hospitals absorb resources in terms Cath Lab utilisation or bed, and even if for a reduced amount of time, because their final destination is not the Cardiology Ward, must be taken into consideration.

The reason behind the choice of these categorisation is based on different path followed by patients belonging to these categories, which is essentially driven by the arrival method and the clinical conditions. While *Elective Patients* arrive at the cardiology ward with an appointment for a specific date and time, pre-scheduled by the hospital, because their health condition is not critical and can be managed by the hospital not immediately, *Urgent* and *Other Patients* arrive randomly at the emergency department DEA, emergency aid system (118) or from another hospital or department, because of their severity status, which must be treated in the shortest possible time. Then, differently from *Urgent* patients, after the cardiac catheterisation procedure *Other Patients* are transferred to their source of arrival.

In order to combine the two classifications of patients, by arrival type and by clinical status, it has been computed the estimated percentage of *DEA, 118* and *Other Arrivals* of *Urgent* and *Less Urgent*, since for *Elective* the two classifications are perfectly matching and *No Problem* patients are assumed to have a spontaneous arrival at DEA, not contained in the data below. Firstly, according to the percentage without elective of each of the arrival types (reported in ***Figure 23*** *Cath Lab Patients divided per Arrival Type),* expected number of *Urgent* and *Less Urgent* for each type has been computed as follow:

		Expected Urgent Patients	Expected Less Urgent Patients
118	*45,1%*	354	75
DEA	*36,8%*	289	61
Other	*18,1%*	142	30
Total		785	166

Figure 26 Expected Urgent and Less Urgent Patient per arrival type

Since it is important to remember that flows concerning other hospitals, other public/private facilities and other department of the hospital will not be considered within this analysis, it is necessary to find a criterion for identifying *Other Arrival* patients, starting from the information contained in the SDO. For this reason, it has been assumed for *Other Arrival* type patients a standard duration of the hospitalisation, since in this case their length of stay consists only of post-recovery procedures and after their clinical status is stable, they are transported to the ward. In detail, for Urgent patients Other Arrival patients have been associated with a LOS from 2 to 4 days, whereas, because of the lower criticality, for Less Urgent patients, the ones corresponding to other arrivals are identified with LOS equals to 4 days, respectively an estimated average of 2 days before the operation and 2 days after the operation. This somehow simple assumption is quite accurate and coherent with the expected values computed previously, because as reported by ***Figure 27***, the difference between expected values and real values obtained applying the selected criterion is acceptable.

	Other Expected	*Other* Assumed	*Expected %*	*Assumed %*
Urgent Patients	142	146	18,1%	18,6%
Less Urgent Patients	30	31	18,1%	18,7%

Figure 27 Assumed and Expected number of Other Arrivals Patients for Urgent and Less Urgent clinical conditions

The patients assumed to arrive by Other Arrival type were removed from 118, since it was reasonably that their arrival and transportation is done with an ambulance, similarly to arrival by emergency aid system. The assumed number of patients for Urgent and Less Urgent classes is reported in the ***Figure 28***.

The final classification and assumed number of patients for each of the categories is reported in the ***Attachment 5***.

	Expected Urgent Patients	Expected Less Urgent Patients	Assumed Urgent Patients	Assumed Less Urgent Patients	Expected Total %	Assumed % Urgent Patients	Assumed % Urgent Patients
118	354	75	350	74	*45,1%*	*44,6%*	*44,6%*
DEA	289	61	289	61	*36,8%*	*36,8%*	*36,7%*
Other	142	30	146	31	*18,1%*	*18,6%*	*18,7%*
Total	785	166	785	166	100%	100%	100%

Figure 28 Assumed percentage of Urgent and Less Urgent patients for each of the arrival types

After having analysed available data and categorised into main flow classes the patients entering the Department, the next step was obtaining a detailed and clear description of procedures followed by different categories, highlighting the interactions between main areas of the Department and the other areas external connected with the Department itself. For this purpose, activity diagrams were realised, depicting the flow of different types of patients from their arrival to their discharge from the hospital. The detailed description of processes, discussed in the following sections, is necessary for the identification of all possible bottlenecks and for achievement of any improvements.

5.2.1.1 Urgent Patients

Urgent patients' scheme is reported in the ***Attachment 2***. Patients may arrive at Cardiology Ward in two different ways: spontaneous arrival at DEA (*Dipartimento d'Emergenza e Accettazione*) or by ambulance through a call to emergency aid system 118. For the latter, if there are already provisions regarding Fast Track agreement between ambulance staff and hospital's personnel and operations center and if there is already a confirmed STEMI or Urgent N-STEMI diagnosis with ECG, in case of availability of the Cath Lab, the patient is transferred directly to lab, without passing through DEA. Of course, the application of Fast Track procedure requires perfect coordination and exchange of information between different parties involved. Otherwise, in case there is no coordination, or the diagnosis is not confirmed, or the Cath Lab is not available/not ready, patients are transported to DEA. In the DEA, irrespectively of their arrival, patients are assigned a code by triage's nurse and they are visited by doctor on duty, which execute the ECG and asks for advice of a cardiologist. In this case it is possible to divide patients among Urgent and Less Urgent, according to precise clinical standards agreed between DEA and Cardiology. Based on the diagnosis, there are three main possible scenarios:

Scenario One. If the patients' diagnosis is STEMI or Urgent N-STEMI and if this diagnosis is confirmed, they are immediately transported in the Cath lab. In case the lab is not available or not ready, the DEA's doctor on duty, advised by cardiologist previously called for a consultancy, decides whether let patients wait in the DEA, until the lab is ready; there is a maximum period of 30 minutes that a STEMI or Urgent N-STEMI patient can wait, called *Tempo di Reperibilità*. During this time, if the unavailability is not caused by another procedure being performed, Cath Lab must be set up and staff must be available on call. Once the lab is available and ready, the patient is transferred to Cath Lab, following a series of procedures of transportation and movement, and the operation is performed, reducing at minimum preliminary activities needed for the operation; in this case, time is a crucial variable, since the faster the procedure is made, the higher are possibility of success of the operation. In any point of the process, if patients decease, they are *Dismissed as Dead* and transported to UTIC for completion of all documentation related to patients and for undertaking all procedures related to realisation of death. In case instead the operation is successful and the patient is alive, post-operation procedures are completed and a 30 minutes monitoring is done in Cath Lab Bed Area to evaluate patients' response to procedure and their potential need of intubation; in case intubation is needed, patients are transferred to a specific intensive care unit, external to the Cardiology ward; otherwise, patients are transferred to UTIC. In the UTIC units, post operation monitoring is made, as reported by ***Figure 29****.* If patients are still alive after this period spent in the intensive care unit, whose duration depends on patients' need and their response to treatment, they are transferred to Cardiology Ward, since their necessity of care is lower. After hospitalisation and completion of treatments needed, patients are ready to be moved to their house, to rehabilitation facilities or long-term care institutions, depending on patients' situation and needs.

Scenario Two. In case instead the diagnosis is N-STEMI Not Urgent or Not-Stable Angina or Exertional Angina, meaning in case patients can be labelled with Less Urgent, depending on Cath Lab availability they are admitted to UTIC unit waiting for the operation. After the operation, taking into consideration all complications may emerge during patients' journey, they are either transported to Reanimation Ward or directly to UTIC where post operation monitoring is performed and later, after their health status is stable and requires less care, moved to Cardiology Ward to complete their hospitalisation. The difference with respect to previous scenario is time Less Urgent patients wait before undertaking the operation: since their severity is lower than the one of Urgent patients, they can wait also a couple of hours or even a day before the execution the operations.

Scenario Three. In this case it is possible that patients arrive at DEA or by ambulances, complaining of STEMI or N-STEMI symptoms, but there is no correspondence with ECG results of these diseases. In this case, patients are immediately dismissed, or dismissed after some cardiological check-up or coronary arteriography, since no medical issue has been confirmed.

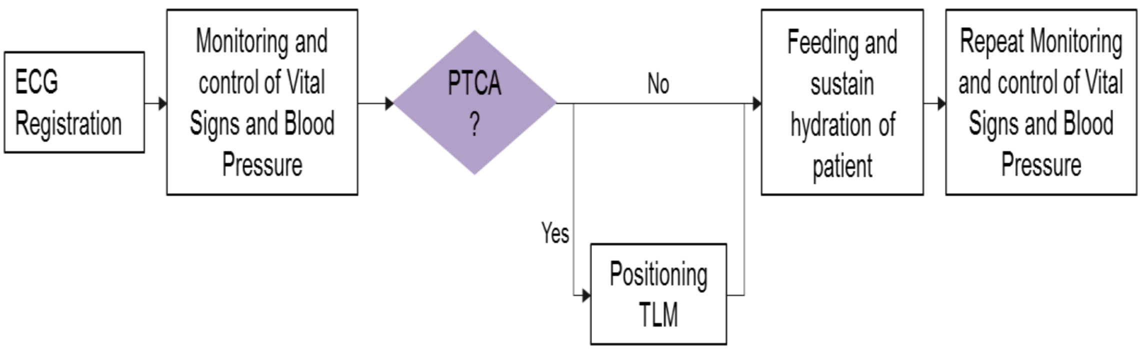


Figure 29 Post Operation Monitoring

5.2.1.2 Elective Patients

Cardiac catheterization procedures can be also done in case of elective patients, whose process is reported in the ***Attachment 3***; in this category in fact, patients arrive at the cardiology ward in a specified time and date, booked in advance and scheduled within a given period of time, depending on the severity and necessity; most of the times, elective patients are patients that needed a less critical operation, which may be performed in a subsequent hospitalisation. Elective admissions can be either of Ordinary Recovery type or Day Hospital/Day Surgery procedure; in this analysis, only ordinary recovery will be considered, since Day Hospital/Day Surgery procedures absorb less resources, because of the lower risk related to the execution of this procedure. Elective patients arrive at the cardiology ward at the specific date and time scheduled, they are registered by an administrative nurse. This operation is not time consuming, since elective patients one or two days before their recovery perform a Pre-Recovery operation, in which all the relevant information, documentations to provide and data are collected and inserted in advance, so to reduce the time spent for registration in the recovery day. In their pre-operation recovery, patients follow a list of activities and rules, as reported in the ***Figure 30Error! Reference source not found.***. After the completion of all necessary steps, in case no emergency happened, patients are transferred to Cath lab, the room is prepared, cleaned and sanitized for the new patient's arrivals, patients are prepared, with electrodes and drip correctly placed, and anesthetize. Then the procedure is performed and in case of success, post-intervention procedures are taken patients are dressed, all organic and dangerous wastes are removed. Generally elective patients are characterized by a higher success rate, since their condition of elective is based on a lower criticality in clinical terms. However, in case of complications, after the procedure they are transferred in the UTIC, otherwise they are carried over to their bed Cardiology Ward. Also in this case, as reported in ***Figure 29***, post operation procedure and monitoring is performed to evaluate the status of patients. After that, if patients need another operation but not immediately, an appointment for another procedure is reserved in advance, depending again on necessity of the intervention; otherwise, patients are discharged with a follow up procedure.

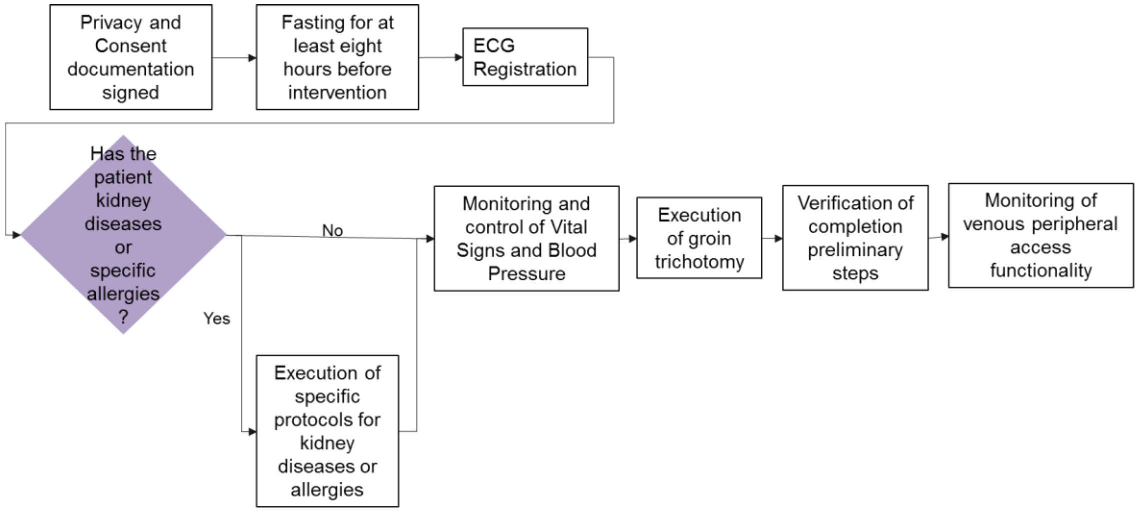


Figure 30 Pre Operation Procedures

5.2.1.3 Other Arrival Patients

Even though *Other Arrival Patients* category is not completely within the scope of this analysis, the basic process followed by these type of patients will be analysed, since, as previously explained, they absorb resource of the Department especially considering the utilisation of Cath Lab and bed allocation, which in turns impacts on the path followed by the ordinary recovery of the other two categories; this highlights also a criticality for the Department, since for this category of patients the costs are entirely sustained by the Cardiology, whereas part of the fictional revenues associated with DRG are given to Spoke Hospitals, Other Departments or other public facilities. *Other Arrival Patients* type has the same clinical status of Urgent and Less Urgent Patients categories, differing from the latter for the arrival method. This however modifies only post-operation procedures, since after having performed the required cardiac catheterisation procedure and the necessaries post operation procedures and monitoring, as assumed previously (see ***Figure 29***), they spend in the UTIC unit from two to four days for Urgent clinical condition and only two days for Less Urgent Patients. Similarly, the activity diagram is presented in the

Attachment 4.

5.3 Criticalities

During the current state analysis, as result of the interaction with main users of the system, it has been possible to identify principal inefficiencies and issues emerged; having a clear understanding of these problems represents starting point to the definition of a future state condition. The criticalities discovered are reported in more detail in the following sections.

5.3.1 Long-term care

One of the main problems faced by the Cardiology Department is scarcity and overcrowding of long-term inpatients facilities, for patients requiring an assisted long-term recovery and in some cases also rehabilitation programs; this, in fact, impacts on the department with a higher length of stay for these patients, not increasing or even reducing the turnover rate, which essentially limits the possibility of providing higher level of services and performances. It is important to consider that, in contrast to a manufacturing company, in a healthcare facility it is not allowed to have *buffers*, meaning that in case *workstations* and *locations* are saturated—as for instance no beds are available or the operating room is already busy— patients in principle cannot enter the facility and wait during the process for these resources, but they must enter the facility only when resources and locations are available, or available in the short. Having parts of resources and locations occupied by patients who requires a different type of care is therefore a waste of resources. This problem is a strictly related to a social side of Italian healthcare systems, whereby hospitals in some situations become shelter for people needing social assistance, rather than medical assistance. Especially in the case of a cardiology department, whose patients have a higher average age, large part of them cannot receive the necessary assistance in their domiciliary context, increasing the length of their hospitalisation and their bed occupancy, which impacts on the total number of admissions and recovery made by the department.

5.3.2 Lack of standardisation and measurement system

One of the main problems that weigh heavily on the minds of the Cardiology Department Chief, Dr. Massimo Giammaria, was the lack of standardisation of different processes carried out in the healthcare context. Need for more standardisation is a crucial aspect when considering improvements of healthcare systems, through the application of industrial principles; the standardisation in fact enables the reduction of errors and decreases also the possibility of making mistakes, which is fundamental in an extremely variable environment as the healthcare ones. Differently from a typical production company where errors reduce the wastes throughout the process, which in turns increases company's monetary savings, when dealing with reduction of errors in healthcare system this implies a higher level of care provided, since it is aimed at reducing errors on patients' journey. The lack of standardisation is directly related to another big issue of the department, which is lack of appropriate measurement system. One of the first criticalities emerged in the analysis was the difficulties of finding data and precise measurements related to important variables; also in cases data and measures exist, it was not so trivial to find them, because of their difficult accessibility, incompleteness or incorrectness when reported in electronic form. In fact, also in the analysis previously explained, some of the data manually measured by the personnel were not inserted in the information systems or even when inserted, it was complex to display them, since there were not visible or partially visible on the current software interface; the influence of information systems on the Department will be better explained in the following paragraph. Of course, lack of precise and updated measurements complicates the understanding of current system; however, the Cardiology Department is trying to move to an Hospital 4.0 version, because of the importance of an accurate analytical analysis of their current situations for a higher quality of care provided.

5.3.3 Information systems

Similarly to production-like problem, it was clear that the information system structure was extremely complicated and in some way increased the difficulties throughout the process. The problem was essentially related to the large number of different information system used within the Department, caused by the extreme specificity, in terms of scope and utilisation, of each of the system adopted. The entire city of Turin, to enable the availability of all patients' medical history information contained in the Electronic Medical Record (*Fascicolo Sanitario Elettronico*) on the regional territory by different structures, adopted a unique managerial software (called A for privacy reasons); however, since this software was not able to register some of diagnostic information related to the Cardiology Department, as surgery data (ECG, Holter test, stress test and imaging data) or external flows of patients, a different managerial software (similarly called B) has been adopted by the Department for handling all the information and data not processed by A. After having inserted this information in the software B, a document provided by software B must to be put in in the software A, increasing the complexity of the electronic medical records drafting. This software B is Cardiology-specific and nowadays it is used only by the Cardiology Department of Maria Vittoria Hospital, but it will be shortly adopted by all Cardiology Departments of Turin. A and B are not the only information system used by the Department's staff; they in fact have to deal with a software C for inserting all the information related to the use and dosage of therapy dispensed to each patients hospitalised, a software D aligned to the Registry Office (*Anagrafe*) for ensuring that the code associated with each patient is unique and no swaps are possible, a software E for management of medical records, integrated with software A but however a different software and lastly a software F for accessing all the information and statistics within the ASL. In addition, the Cath Lab itself uses a particular software for storing all imaging and data related to each operation performed within the Lab. From this brief explanation it is clear that the personnel has to deal with a large number of different software, which adds complexity to an already complex process and makes it harder the shift to a more electronic-based version of the hospital; moreover, because of the increasing time required for entering all the necessary information, there is a reduction of the time and the focus of personnel on patients' care. Another problem caused by the challenging information structure is the rising possibility of errors or wrong information insertion, leading to not coherent data within different information systems and it; also within the analysis of the data previously explained, some of the data provided by the different software were not coherent or not complete, leading to some assumptions for relating different data and differences in term of assumed and expected value.

5.3.4 Other Patients Arrival

As previously mentioned, the Hospital is a Hub Hospital, when considering the Cardiology Department, because of the presence of a Cath Lab, enabling the facility to perform invasive cardiac procedures. Part of the patients flow interacting with the Lab is coming from other hospitals (Spoke), other departments or other public and private facilities. Especially in case of other hospitals and other departments, this type of patients creates a misrepresentation of the actual performances of the Department. As explained in *Chapter 1* ASLs are not remunerated according to the actual value of the performance made, but based on a specific criteria, territory-specific; however, since DRG is a standard measure of cost/revenue associated with homogenous classes of patients, ASLs are also evaluated on the basis of the total amount of DRG performed within the Hospital and within each Department. In case of procedures and operations performed to patients which are not hospitalised patients of the Department in its strict meaning, this implies that only part of the DRG is assigned to the Department. In this case, since a significant part of the patients which requires a cardiac catheterisation procedure is coming from other facilities (as evaluated in the Catheterisation Lab Analysis the around the 15%), this implies a lower amount of DRG associated to these patients; in other words, while the entire amount of costs is spent by the Department, in terms of resources and location consumptions, the largest share of *remuneration* is assigned to the original source. This is however a difficult point for public healthcare facilities, especially ASLs, since they are financed through a given method (*quota capitaria*) and evaluated in terms of indicators and performances on another method (for performance through DRG), which increases from an administrative and organisational point of view the complexity of the system.

5.3.5 Manual processes and communications between areas

Another problem emerged during the analysis of the current state concerns the massive utilization of the phone calls. Because of the interaction of different users located in different areas of the Department or even of the entire block of the hospital, phone calls are essentials to quickly communicate with other users, to demand for bed or other resources availability, for information about patients and about transports between different areas. This problem affects primarily staff work, because it could be bothersome to receive a huge amount of phone calls or being called twice from different operators for the same tasks; furthermore, it may also impact on the patient experience, because of misunderstandings between personnel or non-communication of some important information to patients. Finally, a criticality is represented by the great number of printed documents on which almost all hospitals rely. Even though the Department is trying to shift to a more electronic-based documentations, all documents and reports are all printed on paper, in which all information are manually inserted by personnel and manually checked one by one by Department Chief; some of the sheets are printed only for operational purposes then are discarded after their utilisation. The huge set of documents printed and not inserted in the system is reachable only through the hardcopy of the clinical folder, hence folders must be kept in order to verify all information of each patients hospitalised. Moreover, having either a paper-based clinical folder and an electronic-based one doubles time and effort necessary for performing this activity; in particular, in the Department there is a doctor which is in charge of the translation of the clinical folder from the paper-based version to the electronic-form. The huge amount of paper documents represents a waste of space, because their storage has an impact on the Department, but it is also a waste of time for their insertion in the information systems and in case of necessity to check a specific document.

5.3.6 Transportation

As presented in the introduction to this chapter, the Cardiology Department is structured on three levels of the hospital block, hence transportations of patients through different floors is a critical aspect of each process performed within the entire Department. Patients are transported directly with their beds, since they are equipped with wheels for movements, which whilst reduces any possible bottlenecks on gurneys availability for transports, it increases the difficulties in transportation and positioning on beds within the elevators, caused by beds and elevators sizes. However, in some cases, as transportation from DEA or Ambulances, patients are moved in gurneys, because they are not hospitalised yet, hence there is not a reserved bed. In the building where Department is located, two elevators are available, serving not only the Cardiology Department, but also Ophthalmology, Otolaryngology, Orthopaedics, Orthopaedic Surgery, a training centre and several surgeries and intensive care units. This of course implies a higher flow of patients using elevators, increasing waiting times for transporting patients to the Cath Lab or to bring them back to Ward. Moreover, the transportation times are not equal for all patients, since depending on the severity of health status of patients transported, transportation conditions may change: in case of critical patients, different members should assist the patients during this movement (as for instance a specific doctor or a one in charge of resuscitation) and a higher carefulness is required when considering drips or other equipment to which patients are connected. Another critical point of patients' transportations is related to personnel in charge of this activity; in fact, different actors are involved, depending on the type of movement. For all transportations from the Department to external locations or to Cath Lab, there is a specific company ASSISTE, responsible for transfers of patients and all items (as test tubes, analysis from other department); in the particular case of transportation from/to Cath Lab, ASSISTE members must be escorted by a Nurse or a Certified Assistant Nurse associated with the Lab. When instead patients' transfers are related to different parts of the Department, these are performed by Certified Assistant Nurses or Nurses of either the Cardiology Ward or the UTIC unit. The main problem behind transportation is that ASSISTE company is in charge of transportations in the entire hospital, not only the Cardiology Department, which in turns increases the time spent for moving and transporting patients because of availability of ASSISTE members, especially because their working hour is from Monday to Friday, 7:30 to 15:30; this implies that in the remaining time slots, transportations and movements are performed by Certified Assistant Nurses and Nurses, which increases the amount of work they must perform, reducing time spent for patients' care and monitoring.

Chapter 6 Results and Future Solutions

6.1 Model construction

After having obtained a general picture of the processes related to Cath Lab Patients, mapped almost all possible scenarios to patients associated with the Lab and collected available necessary information, a simulated model representation of the different flows (personnel, equipment, plant and especially patients) associated with cardiac catheterisation procedure was created for identify possible areas of improvements.

To create the model, a healthcare context-based software, FlexSim Healthcare has been used. The strength of the software is the patient-centred virtual system, in which almost all processes and activities are modelled based on patients, in order to improve the quality of service provided by hospital and in turns increase patient's satisfaction. Therefore, patient preferences, values, needs and information are essential for the construction of the whole virtual organization and for the management of all other items.

6.1.1 Department layout and resources

In order to run the simulation using FlexSim Healthcare software, it was necessary to re-create a computer-based version of the Cardiology Ward of the Hospital. Since a simulated model is a simplified version of the real model, some assumptions have been introduced to handle more easily the simulation and reduce part of the complexity associated with the Department; for instance, not the entire Department was modelled, some of the parts as Electro-Physiology lab or the Surgery have been omitted, since these do not directly impact on the Cath Lab patients' path, which is the scope of this analysis, hence their modelling would have increased the unnecessarily complexity. The first step was the re-creation of the layout of the department, adding main objects and location to the different areas playing a role in the process analysed, as shown by the picture below (***Figure 31***).

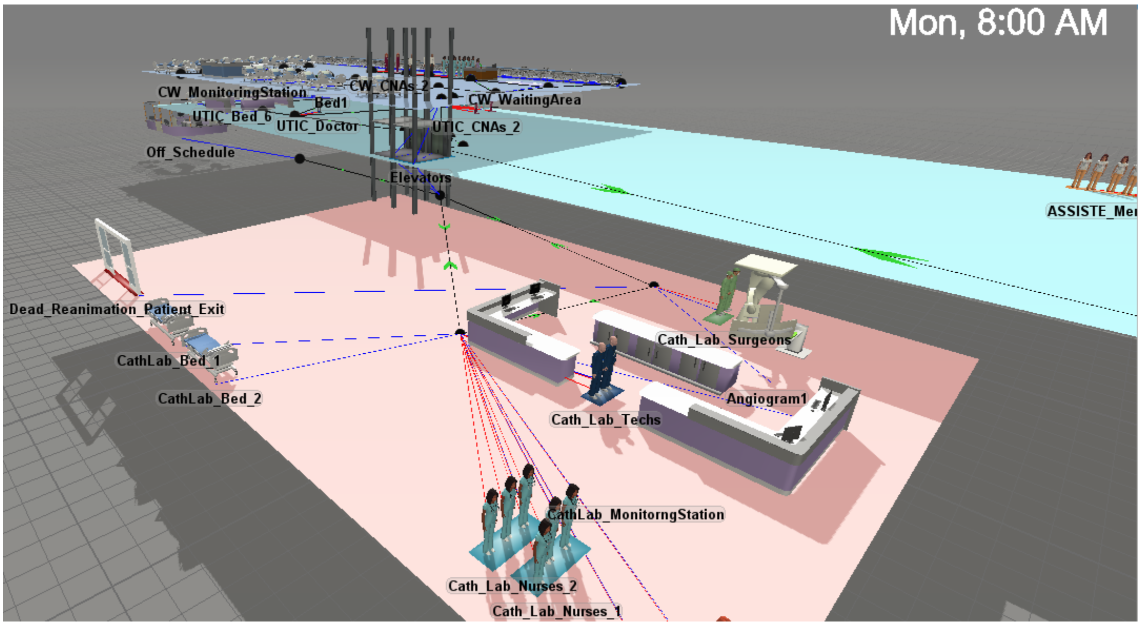


Figure 31 Homescreen of Maria Vittoria Hospital Cardiology Department on FlexSim Healthcare 5.3.10

Furthermore, an extremely simplistic version of the Emergency Department has been considered to account for the interactions with the Cardiology Department, in modelling Urgent and Less Urgent patient arrivals.

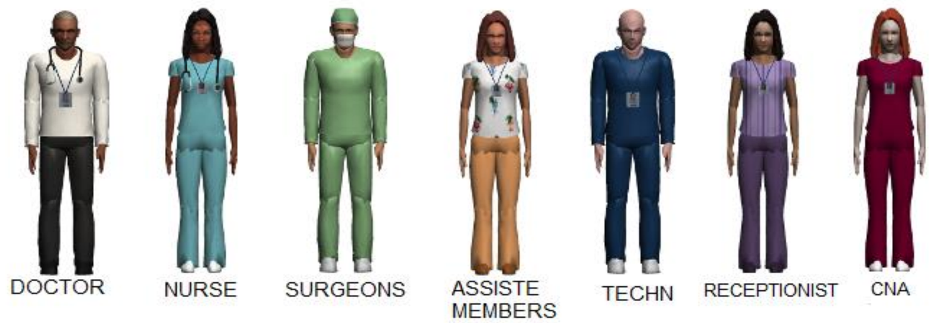


Figure 32 Staff Resources added on FlexSim

Once create the basic layout and basic objects inside each area, it was necessary to add staff (***Figure 32***). Starting from the data provided by Dr. Giammaria, the following different typologies of staff were introduced:

- General doctors for UTIC, Cardiology Ward and DEA;
- Nurses in each of the area;

- Surgeons, doctors specialized in cardiac catheterization procedure, performed in the Lab;
- Members of ASSISTE, external company entitled of the transportation and movements of patients from DEA and from/to Cath Lab;
- Technicians in the Cath Lab;
- Receptionist, namely administrative as nurse for registration procedure and all documentations of dismissal;
- Certified Nursing Assistants, which perform routine tasks helping nurses.

The resource availability in the system is reported in the ***Table 5*** below.

*Table 5 List of staff resources allocated per each different location (*An afternoon and night doctor have been added ideally only to CW to cover the shift;**Simplified Version; ***Up to 4 members of ASSISTE have been associated only to Cardiology Department).*

Resources	Cath Lab	UTIC	Cardiology Ward	DEA**
Doctors	-	1	2+2*	1
Nurses	6	6	6	1
Surgeons	2	-	-	-
ASSISTE	-	-	-	4***
Tech	2	-	-	-
Receptionist	-	-	1	-
CNAS	2	2	4	-

Also in this case some assumptions were made to simplify the model; in particular for ASSISTE members, which are entitled of patients transportation from the DEA and from/to Cath Lab, it has been assumed to have from two up to four dedicated units for transportation of Cardiology patients; this is an assumption made based on the observations of the transportation within the hospital, because there is a more complex organisation of ASSISTE members, since they are associated to the entire hospital. In addition, also for Cath Lab nurses and certified nurse assistants a simplification was made, since currently they are divided on Cath Lab and Electro-Physiology Lab for each shift, while in the model are only associated with the Cath Lab; in order to take into account this division of the work, also Cath Lab Nurses and Certified Nurses Assistants number is ranging from 1 to 3 for Nurses and from 1 to 2 for CNAs. Another assumption made is on the number of gurneys available in the Department; it has been already reported that generally patients are transported with their beds, if they are hospitalised, but this would increase complexity of the simulation. To overcome this obstacle, a number of gurneys equal to the number of beds has been added either in the UTIC unit and in the Cardiology Ward; this of course is an over-estimation of the exact number of gurneys.

Once added different members, staff shift times and alternate groups were created; in particular, FlexSim Healthcare allow to link different groups of resources through the creation of alternate groups, to model situation in which different resources are used to perform the same activity (for instance, to associate to patients' different groups of nurses) as reported below.

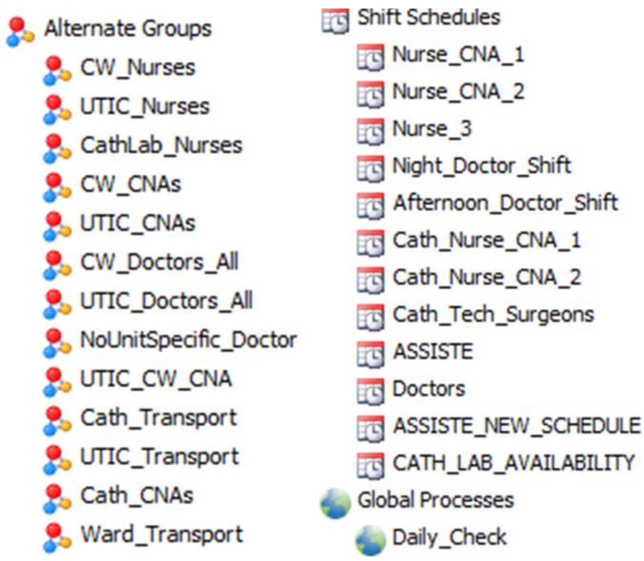


Figure 33 Alternate Groups, Shift Schedule and Global Processes

After having introduced staff and their respective schedule, it was necessary to create the flowchart, in which different areas and location must be connected; this tool is essential, since without the connections between areas and/or objects, patients and staff will not be able to move or interact with objects in the model. Once created the basic layout and the basic flowchart, it is necessary to introduce patients to this model. In particular, different types of patients entering the model are created using the Patient Classification Tools; based on the analysis previously made, six different types of patients were created, to consider the three different scenarios of the Urgent Patients, the Elective Patients path, and two possible arrival from Other Patients; to sum up the following patient classifications were created: *Urgent, Less Urgent, Elective, No Problem, Other Urgent and Other Less Urgent*. In particular, to consider the different priority based on clinical status a different Acuity Level has been associated to patients, from 6 to Urgent up to 1 for No problem as reported by the figure below.

	Track	Visuals	Acuity
Data Types	text	text	number
Urgent	Urg__LessUrg	Urgent	6.00
Less_Urgent	Urg__LessUrg	Less_Urgent	4.00
Elective	Elective	Elective	3.00
No_Problem	Urg__LessUrg	No_Problem	1.00
Other_Urgen	Other	Urgent	6.00
Other_Less_	Other	Less_Urgent	4.00

Figure 34 On the left, Patient Classification tool. On the right, different patient visuals created for different clinical conditions.

To each of the different classifications a different patient visuals was associated; this helps in the visualisation of the patients while running the simulation and additionally, garments colour was related to the degree of criticality of patients' health status (Red-Urgent, Yellow-Less Urgent, Orange-Elective and Green- No Problem).

6.1.2 Patient Track definition

Proceeding in the model construction, the fundamental part was the definition of patient track, which is the series of activities forming the path of each category of patients, from the moment they arrive in the simulation (hence from their arrival in the hospital) until they exit the model, once their hospitalisation is over. In this case, three main patient tracks were defined: *Urgent_&_LessUrgent*, *Elective* and *Other*; the reason behind this choice was derived from the process analysis, since it has been already pointed out the difference of elective patients, especially in their arrival to the hospital, because they arrive directly at the Cardiology Ward for the registration, without interacting with the emergency department and of other arrival patients, whose length of stay is different from the other patients, since they are transported after the post operations procedure to their primary facility. Afterwards, based on the Activity Diagrams constructed, patient tracks have been modelled, replacing processes with activities. Since Elective patient track is almost linear, because their recovery is scheduled, it was easy to translate in terms of FlexSim HC activities different steps of their path; the only decision point was introduced to take into consideration the relatively small percentage of elective patients needing intensive care recovery after the operation, as reported in ***Figure 35*** below, since it has been estimated only a 0.5% of total elective patients needing UTIC recovery, hence only that percentage after activity *80_RecoveryChoice?* will perform activity from 82 to 84; in case of elective patients, the possibility of unsuccessful procedure is extremely low that will not be modelled.

Figure 35 Patient Tracks for Urgent_&_LessUrgent patients, Elective Patients and Other Arrival

For *Urgent_&_LessUrgent* and *Other* the path is more complicated, since after their arrival in the model, a certain percentage of patients is directly sent to the Cath Lab, following the Fast Track path, for which patients is transported from ambulance to the lab directly with the gurneys. In this case, the personnel of the

Lab estimated that a 25% of the patients of patients deriving from either emergency aid system 118 and other arrivals follows the Fast Track process; considering the estimation made in the paragraph 5.2.1 Catheterization Lab Analysis of Urgent 118 and Urgent Other Arrivals, the following percentages of Fast Track patients were added to the model. In this case the effective number of Fast Track patients was computed based on the initial value of 118 Urgent and Urgent Other Arrivals, then the total Urgent Patients, excluding Fast Track, has been computed considering either DEA or 118 arrivals, as reported in the figure below.

Urgent Patients		Less Urgent Patients	No Problem Patients	*Other Less Urgent*	Other Urgent		
Fast Track	NO Fast Track	135	42	31	Fast Track	NO Fast Track	
88	551				37	109	
% ARRIVAL							TOTAL ARRIVAL
64%		14%	4%	3%	15%		993

% Urgent Fast Track
14%

% Other Urgent Fast Track
25%

Figure 36 Assumed number of Non Elective arrivals and their respective percentages

Then, to consider the different activities patients perform related to the clinical condition associated (namely urgent, less urgent or no problem) a decision point has been introduced for both tracks; in particular for *Urgent_&_LessUrgent Track* in activity 30_Decision_Point, there are three main outcomes:

- If PCI= “Urgent”, the patient will execute activity 40, in which the availability of Cath Lab will be verified;
- If PCI= “Less_Urgent”, the patient will execute activity 50;
- If PCI= “No_Problem”, the patient will execute activity 60.

Similarly, in *Other Track* in activity 30_Decision_Point, there are only outcomes for PCI= “Other_Urgent”, in which the patient will execute activity 40, namely checking Cath Lab availability, and for PCI= “Other_Less_Urgent”, in which the patient will execute activity 50.

In both cases, after the execution of the procedure, based on Lab experience, an estimated 6% of patients requires reanimation in Reanimation Ward or deceased after the operation; hence for both tracks, in activity *100_Transportation_UTIC*, the 94% of patients will continue their path in the model, consequently will be transported to the intensive care unit, while the aforementioned 6% will exit the model (which will be simulated by patient exits in *Dead_Reanimation_Patient_Exit*). Consequently, for *Other Track* after a recovery in UTIC the patients are dismissed, because transported to another facility, *Urgent_&_LessUrgent Track* complete their hospitalisation in the Cardiology Ward and are then discharged.

6.1.3 Patient Arrival Time distribution

Once determine the series of activities followed by different categories of patients entering the Department, it was necessary to edit Patient Arrival objects which regulate the rate at which patients arrive in the simulation model. Firstly, two different arrival areas were created, since as the real facility there is a specific entrance for DEA and a different entrance for other patients which arrives from front entrance of the hospital.

Elective Arrival. Since Elective patients arrive at the Department under appointment, to model their arrival Appointments Arrival Type has been selected.

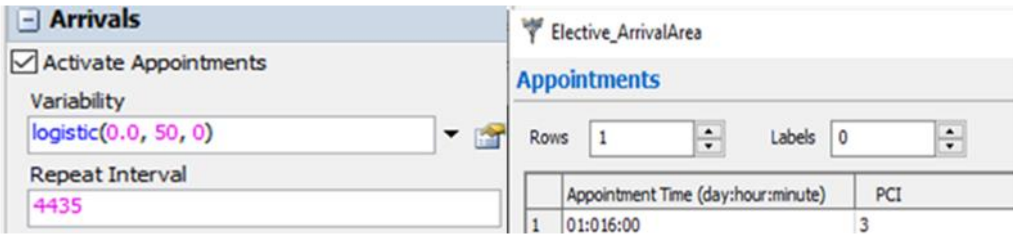


Figure 37 Elective Arrival Type

Elective Patients arrive in the afternoon of the scheduled day, generally around 16:00, but for account of possible randomness affecting how early or late patients arrive for their scheduled appointments, the Variability field has been computed considering the difference of patient's arrival from the standard time chosen. In this case, a distribution fitting procedure has been applied to determine if some of the known probability distributions fit the data in analysis; even though no perfect fitting was found, the logistic distribution with mean 50 min was the closest distribution as reported by the chart below

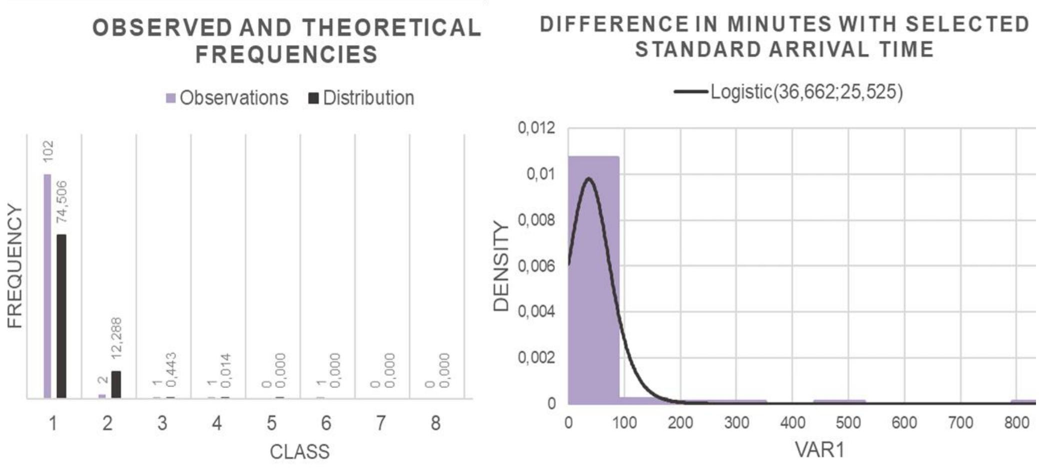


Figure 38 Elective Patients Scheduled Arrival Times distribution fitting

Then because the schedule was done automatically by one of the software used within the Department, it was not possible to derive a general criterion used by the staff for appointments; to estimate the inter arrival time between one elective and the other, hence identify a value for Repeat Interval parameter, the difference in terms of days of admission between Elective Patients was computed, and also in this case the distribution that fits best the data (even if not perfectly) is the Exponential distribution, with average 3,08 days; however, in case of Appointments arrival type is not possible to repeat the arrival based on a distribution, hence it has been assumed that every 3.08 days, around 4435 minutes, a new elective patients will arrive in the model, starting from Monday 1 at 16:00. Of course, this arrival method is applied only for Elective, which in this case means only for PCI 3.

Urgent_&_LessUrgent and Other Arrival. The arrival of all the other patients instead has been modelled in the same way, since irrespectively of their arrival or clinical conditions, their arrival is random. For this reason, Inter-Arrival type was selected, since patients will arrive at the facility at random rates. Then, the percentages computed in ***Figure 36*** are considered for regulates the percentage of each PCI, as reported in the figure below *(**Figure 39**)*, the 64% of arrivals will be of PCI1, namely Urgent patients and similarly for the remaining PCI, except for PCI3 which is associated to Elective and which has been explained previously.

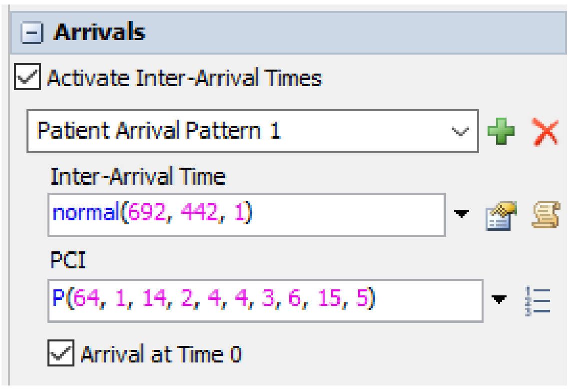


Figure 39 Non Elective Patients arrival type

The next step was deriving inter-arrival times between different arrivals, which is essentially the time, expressed in minutes, from one arrival to the other. Also in this case it has been computed the differences between admissions date and times of all the records associated to Cath Lab without Electives, and similarly to what observed for Electives, there was no match with any of the known probability distributions but the one that best fit the data was the normal with mean 692 minutes and standard deviation 442 minutes.

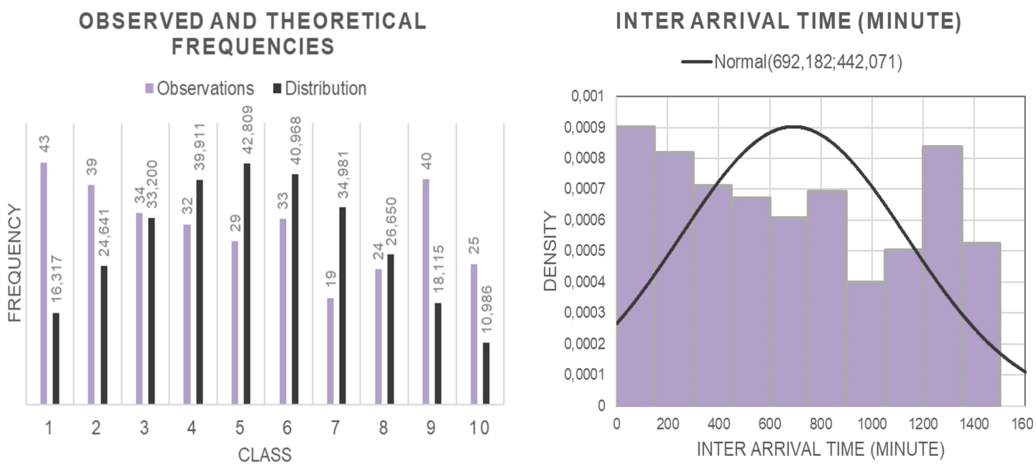


Figure 40 Non Elective Patients Inter-Arrival Times distribution fitting

6.1.4 Activity processing time estimation

After having described the series of activities patients follow during their hospitalisation and defined the way these patients enter the model, it has been necessary to define for each activity the characteristic parameters as required by FlexSim HC. Since times and staff requirements depend on the different tracks, they will be introduced separately.

Urgent_&_LessUrgent Track. In case of *Urgent_&_LessUrgent Track*, as reported by the ***Figure 41****,* the ECG has been assumed to last 15 minutes, considering as staff members the ones of DEA and the cardiologist on duty called for a consultancy. In case the Cath Lab is not ready or immediately available for the operation a maximum time of 30 min has been set as process time of activity 41, since this is maximum time set by the *Regole di Reperibilità.* In case of Less_Urgent patients, since there were no data available on the precise timing of their intervention, based on the estimated total length of stay of Less_Urgent patients (5,5 days in average), it has been assumed that their waiting time in UTIC is distributed as an exponential with average 720 minutes. Then, based on the experience of the staff, some reference values were assumed for all operations performed in the Cath Lab; in this case those reference values have been assume for all three tracks, since either PTCA 00.66 procedure and Valvuloplasty 35.96 procedure are fairly standard interventions whose duration is in 99% of cases ranging from 40 to 60 minutes; in this case, it has been associated the maximum duration of 60 minutes, irrespectively of patient's arrival mode or clinical conditions, as for the Pre Op and Post Op activities.

Urg_&_LessUrg

Activity Table

Name	Predecessors	Next Activity	Process Time	Staff Requirements	Transport Requirements
10_Arrival					
20_Fast_Track?	10	*Based on a condition*			
30_Entering_DEA	LOCKED				
31_EKG	30		15	"Any member from DEA_Nurse"/"Any membe	
40_Decision_Point	31	*Based on multiple cases*			
50_CathLabOpen?	LOCKED	*Based on a condition*			
51_Wait_In_DEA	LOCKED	42	30	"Any member from ASSISTE_Members"	"Any member from DEA_Gurney
52_Transportation_Cat	LOCKED		0	"Any member from Cath_Transport"	K-"Any member from DEA_Gurr
60_Trasportation_UTIC	LOCKED		0	"Any member from UTIC_Transport"	"Any member from DEA_Gurney
61_UTIC_Waiting	50		*exponential(0.0, 720,	"Any member from UTIC_Doctor"/"Any mem	
70_Departure	LOCKED				
80_Transportation_Cathl	61		0	"Any member from Cath_Transport"/"Any m	K-"Any member from UTIC_Gur
90_PreOp	52 OR 80		15	K-"Any member from Cath_Lab_Nurses_1"/"	
100_Cath_Procedure	90		60	K-"Any member from CathLab_Nurses"/K-"A	
110_PostOp	100		15	K-*Requirement 1 of Activity 160*/K-*Requ	
120_PostOp_Monitoring	110		30	K-*Requirement 1 of Activity 170*/R-*Requ	*Requirement 1 of Activity 160
130_Trasportation_UTIC	120		0	"Any member from Cath_Transport"/R-*Rec	K-*Based on multiple cases*
140_UTIC_Recovery	130		*Based on multiple case:		
150_Trasportation_Warc	140		0	"Any member from UTIC_CW_CNA"	"Any member from UTIC_Gurne
160_Ward_Recovery	150		*Based on multiple case:		
170_Discharge	160				

Figure 41 Detailed Urgent_&_LessUrgent Patient Track

It is important to mention some few points about this value: firstly, the precise data concerning the duration of each intervention performed within the Cath Lab (or in general to each intervention made within the Department) are available only on printed form, in the paper version of SDO, which were not accessible for privacy reasons; moreover, the duration estimated regards only the average estimated time for completion of intervention, without considering cases in which the utilisation of the lab is for diagnostic procedures only—as in cases of No Problem patients that may undergone a coronarography 88.56 procedures. The exact timing of beginning and end of each intervention would ensure higher robustness to the model itself, reducing the oversimplification made through this fixed amount of processing time assigned. Finally, UTIC and Ward recovery duration has been estimated, in this case based on the PCI, Urgent or Less Urgent. In fact, for Urgent patient it has been assumed that their duration is equally spent between UTIC and Cardiology Recovery, hence based on the total length of stay of 7.6 days, an exponential distribution with lambda parameter equals to 3.8 days (= 5472 minutes) has been associated for both UTIC and Cardiology Ward Recovery process time; in case of Less Urgent instead, based on the experience and the resulting data, it has been assumed an exponential distribution with average 3 days(=4320 minutes) for UTIC Recovery process times, while a 2 days (2880 minutes) lambda value for Cardiology Recovery.

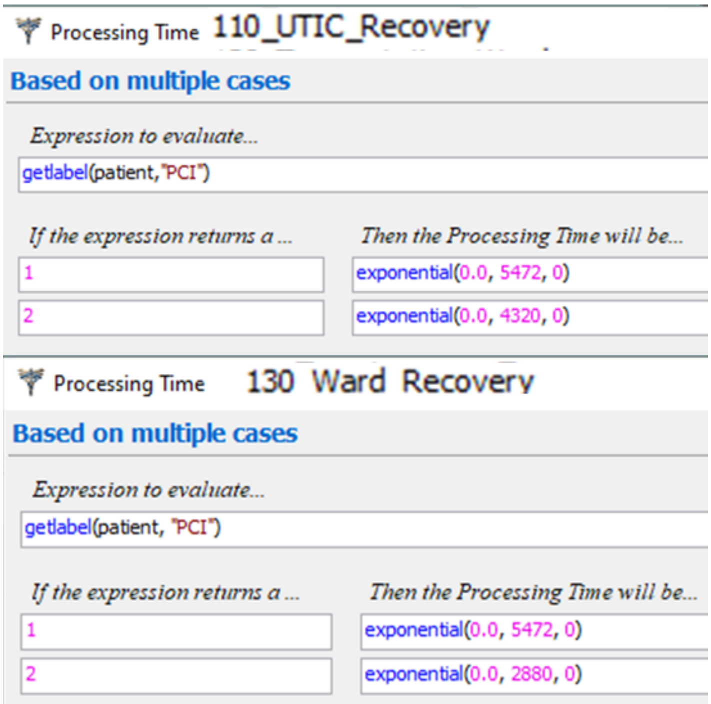


Figure 42 UTIC and CW estimated Lenght of Stay based on different patient classification (Urgent and Less Urgent)

Other Track. For Other Arrival patients there are just few differences with process times introduced for *Urgent_&_LessUrgent Track,* since in this case for Other Less Urgent Patients it has been fixed a 2 days period of time that they wait before undertaking the operation and similarly, a 2 days duration of UTIC Recovery, based on the assumption made on the data analysis paragraph. Instead for Urgent patients, it has been assumed that duration of UTIC recovery is based on an exponential distribution with lambda value equals to 3.6 days, 5184 minutes, since also for Other Urgent patients it has been made the assumption of total days of hospitalisation ranging from 2 to 4 days.

Other

Activity Table

Name	Predecessors	Next Activity	Process Time	Staff Requirements	Transport Requirements
10_Arrival					
20_Fastr_Track?	10	*Based on a			
30_Decision_Point	LOCKED	*Based on m			
40_CathLabOpen?	LOCKED	*Based on a			
41_Wait_In_DEA	LOCKED	42	30	"Any member from ASSISTE_Members	"Any member from DEA
42_Transportation_CathLab	LOCKED		0	"Any member from Cath_Transport"	K-"Any member from DE
50_Trasportation_UTIC	LOCKED		0	"Any member from UTIC_Transport"	"Any member from DEA
51_UTIC_Waiting	50		2880		
60_Transportation_CathLab(Af	51		0	"Any member from Cath_Transport"	K-"Any member from UT
70_PreOp	42 OR 60		15	K-"Any member from CathLab_Nurses	
80_Cath_Procedure	71		60	K-*Requirement 1 of Activity 70*/K-"/	
90_PostOp	80		15	K-*Requirement 1 of Activity 80*/K-*I	
100_PostOp_Monitoring	90		30	K-*Requirement 1 of Activity 80*/R-*	
110_Trasportation_UTIC	100		0	"Any member from UTIC_Transport"/F	*Based on multiple case
120_UTIC_Recovery	110		*Based on a condition*		
130_Discharge	120				

Figure 43 Detailed Other Patient Track

Processing Time

Based on a condition

Choose a condition:

getlabel(patient,"PCI") ==5

If the conditon is true...

exponential(0.0, 5184, 0)

If the conditon is false...

2880

Figure 44 UTIC estimated Lenght of Stay based on different patient classification (Urgent and Less Urgent)

Elective Track. For Elective, a 5 minutes registration time has been assumed, since as reported in the process description of Elective patients the registration is not done on the admission day. Hence, since the arrival is not random and the operation is generally scheduled the next morning between 8:00 and 9:30, a fixed amount of time has been associated to the PreOp Recovery processing time, as estimated difference between intervention date and arrival date. The other processing times are the same presented for the other two tracks, with the only difference that for Electives the length of stay is surely shorter (3 days on average in total), and they are discharged the day after the operation, which allows to assume that either for Cardiology Ward Recovery and for the rare cases of UTIC Recovery the processing times is distributed as an exponential with lambda parameter equals to 1 day (1440 minutes).

Elective

Activity Table

Name	Predecessors	Next Activity	Process Time	Staff Requirements	Transport Requirements
10_Arrival					
20_Registration	10		5	"CW_Secretary_1 of CW_Secretary"	
30_Bed Placement	20		0	"Any member from Ward_Transport"	
40_PreOp_Recovery	30		1021		
41_CathLab_Available?	40	*Based on a con			
42_Waiting_Availab_CW	LOCKED		30		
43_Transport_Cath_Lab_(Af	42		0	"Any member from Ward_Transport"	K-"Any member from CW_Gu
44_Transportation_CathLab	LOCKED		0	"Any member from Cath_Transport"	K-"Any member from CW_Gu
50_PreOp_Procedure	43 OR 44		15	K-"Any member from CathLab_Nurses"/"Ar	
60_Cath_Procedure	51		60	K-"Any member from Cath_Lab_Surgeons"	
70_PostOp	60		15	K-*Requirement 1 of Activity 60*/K-*Requ	
80_PostOp_Monitoring	70		30	R-*Requirement 1 of Activity 70*/K-*Requ	*Requirement 1 of Activity 4
90_RecoveryChoice?	80	*Based on perce	5	"Any member from CW_Doctors"/"Any mer	
91_CW_Transportation	LOCKED		0	"Any member from Ward_Transport"/R-*R	R-"First used from CW_Gurn
92_UTIC_Transportation	LOCKED		0	R-*Requirement 2 of Activity 100*/"Any m	"First used from CW_Gurney
93_UTIC_Recovery	92		*exponential(0.0, 1440,		R-*Requirement 1 of Activity
94_Trasportation_Ward	93		0	"Any member from UTIC_CW_CNA"	R-*Requirement 1 of Activity
95_CW_Recovery	94 OR 91		*exponential(0.0, 1440,		
100_Discharge	95				

Figure 45 Detailed Elective Patient track

6.2 Analysis of Process Improvements

6.2.1 Identification of sources of delay and critical variables

In order to identify areas of changes in the system, a Cause & Effect Diagram has been developed, accordingly to key users' experiences, reporting the main sources of delays in a general Cardiac Catheterisation process, irrespectively of the patients' arrival mode or clinical conditions (see ***Attachment 6*** *Cause & Effect Diagram*). Particularly, the causes reported in purple are the "Correctable" indicate potential areas of improvements, since the remaining are either related to intrinsic variability of different activities (as variability of Cardiac Catheterisation procedures) or related to parameters which are not under the direct control of management (for instance the precise arrival of elective patients or the waiting times of the elevators, since they are shared through different Departments). The "correctable" sources of delays, identified as the ones that can in principle be managed and controlled, are generally related to delays in the preparation of patients or set-up of procedure, to transportation because of inadequate or unavailable staff or related to wrong communication and documentation.

It has to be mentioned that the Department itself already implemented some practices that in literature are used as suggestions for improvements, and these will be presented as follows.

Pre-Hospitalisation of Elective Patients: as explained in their respective process description, Elective Patients one or two days in advance are required to perform some pre-hospitalisation activities, as filling all the information necessary for their hospitalisation or inserting data within the Hospital's system; then their admissions is scheduled in the afternoon before the operation. This simply measure allow the Department to eliminate the possibility of late arrival of Elective patients and reduces delay connected to incomplete documentation (as Consent and Privacy paper which must be signed before the operation).

Transportation of Hospitalised patients with beds: another practice already made within the entire Hospital is the transportation of Hospitalised Patients (namely the ones to whom a bed has already been allocated) through their beds, instead of a gurney or other transportation means. This reduces all possible delays related to transport equipment unavailability, since on one hand hospitalised patients do not need to wait for gurneys or other transportation means availability, because they are already equipped with a movable bed, and on the other hand this reduces the possibility of delay of non-hospitalised patients because of gurneys unavailability. This removes transport equipment unavailability from possible bottlenecks of the Department.

Regole di Reperibilità: in this case rather than a Department-specific provision, it is a widely accepted guideline and standards to which any hospital generally complies with. It has been already stressed the importance of timing especially in case of Urgent Patients (see ***Table 4*** *Clinical Disease associated with ICD-9 Diagnosis Code* for the clinical definition of Urgent Patients). Hence, in order to ensure the 90 minutes timeframe during which an Urgent patient must be assisted, the Department already adopted some rules for availability of Cath

Lab staff and the set-up time of the Cath Lab if needed, limiting to a maximum waiting time of 30 minutes from Urgent Patients' arrival to the effective start time of the operation; in this case, the Department tries to reduce all possible delays or procedure failure related to room preparation or staff unavailability. In the literature, one approach that used to prevent delays that may happen during weekends or after normal working hours is the adoption of a 24/7 availability of a Cath Lab team within the Department; this approach is effective because it completely eliminates or minimises as possible late arrivals or late starts, but it requires significant efforts in staff scheduling and availability, especially when considering Italian on physicians and nurses working time and work shifts.

As reported in the *Chapter 4* ***Error! Reference source not found.*** *Simulation Modelling*, one of the main advantages of simulation is the possibility to change crucial variables and test different scenarios, to discover and determine impacts of changes on the system performances. However, another use of the simulation is related to the identification of bottlenecks and critical points within the system; in this specific case, the Experimenter tool of Flexsim Healthcare has been used to spot the resources and locations which could constitute major sources of delay, coherently to what presented in the ***Attachment 6*** *Cause & Effect Diagram.* In particular to recognise which resources are more troubled when varying the number of patients requiring care, the *Urgent_&_LessUrgent and Other Arrival* Interarrival time was changed, in order to estimate the impact on two main metrics provided by the tool, namely Total Wait Times and Average Length of Stay. Hence. Inter arrival parameter of DEA Arrival objects regulating both *Urgent_&_LessUrgent* and *Other Arrival* was changed from Normal Distribution with mean 692 minutes and standard deviation of 442 minutes (*Scenario 1*) to a Normal Distribution with mean 350 (*Scenario 2*) and a Normal Distribution with mean 1000 minutes (*Scenario 3*), without varying the standard deviation. The three scenarios were testes with 300 replications for each scenario, resulting in values reported in ***Figure 46*** and ***Figure 47***. By analysing data obtained, one first critical point can be identified with the Triage Area; however, this value must be examined considering two main factors: firstly, simplifications adopted for the simulation, especially when considering the DEA department and secondly the fact that DEA is a different Department with respect to Cardiology; hence this data will not be taken into consideration. Another sources of delay in all three scenarios, considering all patients in general, is related to waiting time for ASSISTE Members; this it is not surprising, since the transportation of patients was already marked as criticality of the Department. In addition, in Scenario 3 in particular it can be observed that UTIC staff, either UTIC nurses or UTIC doctor, are among the major sources of delay. Also in this case it has to be considered that staff allocated in the model reflects the minimum staff configuration and in cases of higher availability of personnel (no personnel in vacations, sick days or medical congresses) the UTIC staff is the first to be increased.

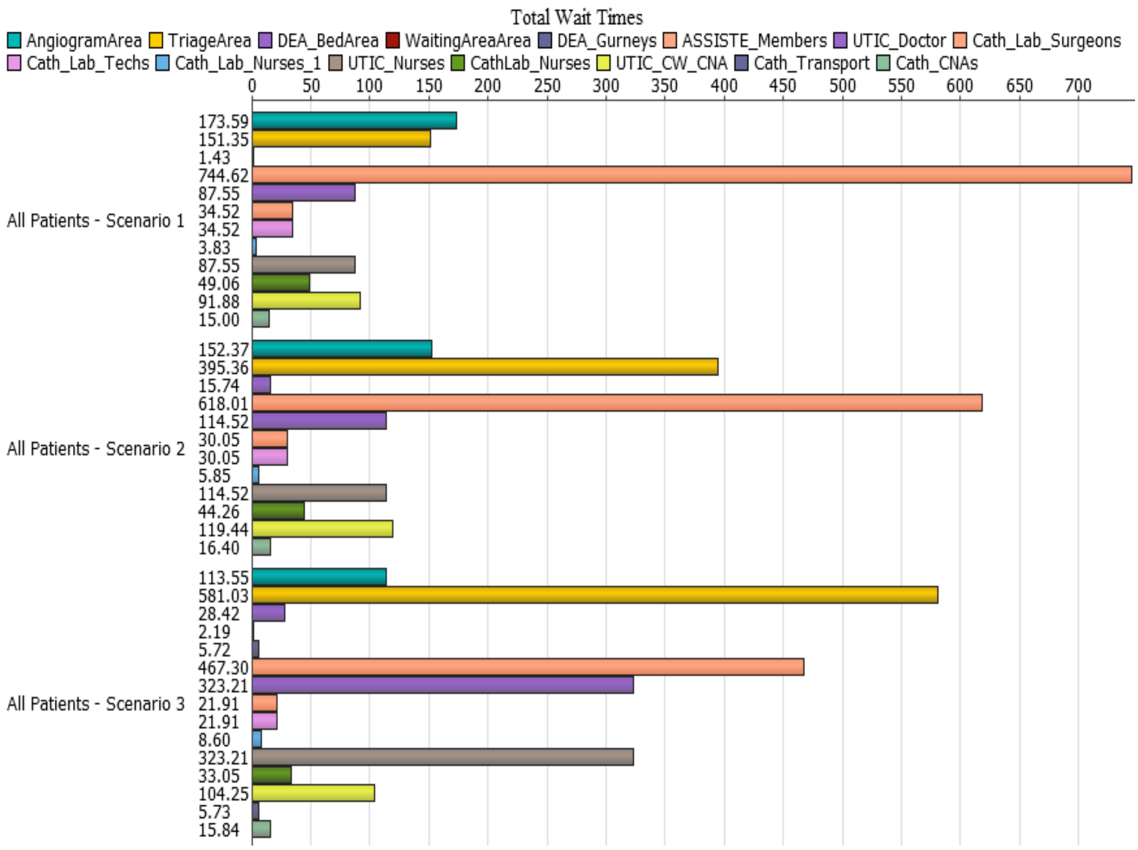


Figure 46 Total Wait Times of Scenario 1, Scenario 2 and Scenario 3

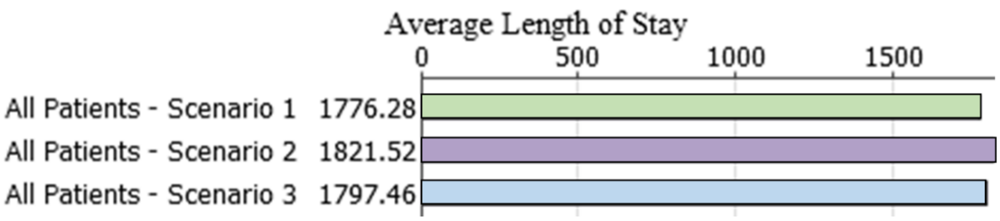


Figure 47 Average Length of Stay of Scenario 1, Scenario 2 and Scenario 3

6.2.2 Scenario definition

Based on the previous analysis and considerations, different solutions and scenarios were tested on the Experimenter Tool of FlexSim Healthcare, to see the effects of changes in two crucial variables (namely Cath Lab Nurses and ASSISTE Members) on Total Wait Times and Average Length of Stay. In particular, their features were varied over a total of 8 scenarios, as displayed in ***Figure 48*** . It is therefore necessary to explain the reasons behind the selection of these two variables in more details.

Cath Lab Nurses. As reported previously, the Hospital is supporting substantial investments for the construction of a new Electro-Physiology Lab in front of the Cath Lab —a single machinery needed for electro-physiology procedures cost over € 400.000. This relocation at floor -1 of the other Lab will facilitate the operations and increase the efficiency also for Cath Lab, since currently Cath Lab Nurses and Certified Nurse Assistants share their shift between the two different labs located on two different floors. Hence moving the Electro-Physiology Lab in front of the Cath Lab will guarantee for Cath Lab Nurses and Certified Nurse Assistants to allocate properly their time, avoiding excessive motions or waste of time. Consequently, it is important to see a expected impact of construction of new Electro-Physiology Lab in terms of Cath Lab Nurses per shift, varying from 1 (minimum possible, considering shared allocation between two labs) and 3 (maximum possible, considering joint allocation between two labs, since if needed all units can be allocated 100% to Cath Lab and similarly for Electro-Physiology Lab).

ASSISTE Members. It is evident that ASSISTE Members represent one of the biggest sources of delay, mainly due to fact that they are not univocally allocated to the Department and that their work shift is scheduled in a different way from the rest of the personnel of the Department. In this case, it will be tested a number of ASSISTE Members varying from 2 (minimum number assumed for a transport) to 4 members specific for the Cardiology Department; moreover, it will be extended their time schedule, from 7:00-15:30 to 7:00-18:00. However, it has to be mentioned that it was not possible to obtain precise and detailed information and data about the personnel of ASSISTE associated with the Cardiology or their scheduling; consequently, while the time schedule is the actually performed schedule, the number of members is just an estimation provided by Cardiology staff and not the precise number associated to the ward.

Experiment Variables	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Cath Lab Nurses	1	3	1	1	3	3	1	3
Cath Lab Nurses 2	1	3	1	1	3	3	1	3
ASSISTE	2	2	4	2	4	2	4	4
ASSITE_Schedule	ASSISTE	ASSISTE	ASSISTE	ASSISTE_NE\	ASSISTE	ASSISTE_NE	ASSISTE_NE	ASSISTE_NE

Figure 48 Experimented Scenarios

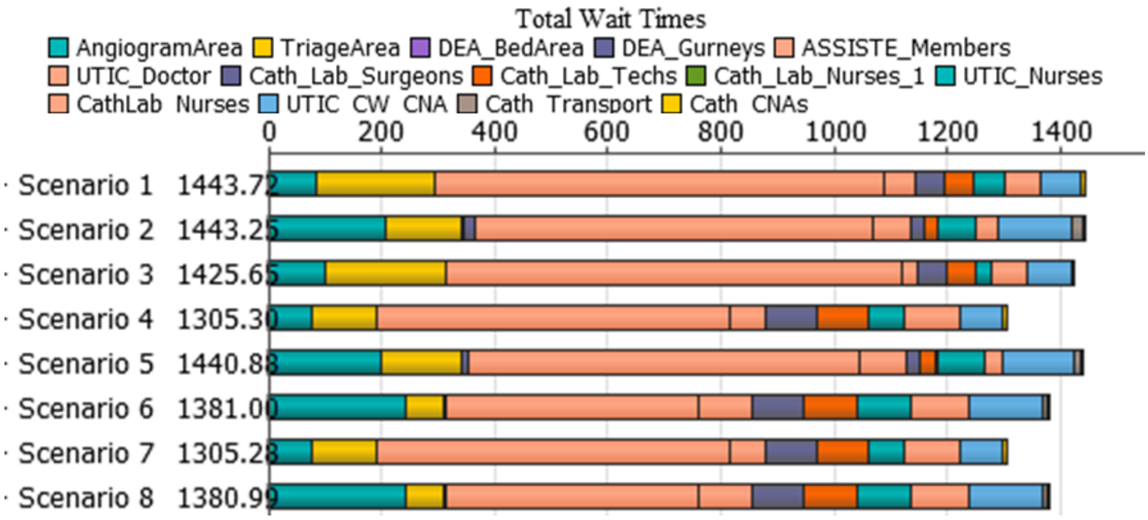


Figure 49 Total Wait Times per Scenario

	% Δ Total Wait Times	% Δ Average Length of Stay
Scenario 2	-0,03%	11,53%
Scenario 3	-1,3%	-9,44%
Scenario 4	-9,6%	-4,01%
Scenario 5	-0,2%	9,13%
Scenario 6	-4,3%	13,35%
Scenario 7	-9,6%	-4,01%
Scenario 8	-4,3%	13,35%

Figure 50 Percentage variations of Total Wait Times and Average Length of Stay

6.2.3 Outcomes discussion and optimal scenario selection

Results of the Total Wait Time and relative variations of Total Wait Times and Average Length of Stay for different scenarios are reported in figures below ***Figure 49*** and ***Figure 50***.

From values obtained it is possible to the optimal scenario in terms of Average Length of Stay of Patients is Scenario 3, in which 4 ASSISTE Members are allocated, rather than the minimum number of 2; in terms instead of Total Wait Times, the optimal scenario is Scenario 4 followed by Scenario 7. It is evident that a change to ASSISTE Members variables reduces either the total waiting time spent by patients or the average length of stay of patients, pointing out the criticality related to transportations. However, since ASSISTE is an external company in charge of transporting patient throughout the hospital, a possible modification of existing contractual relationship with the Hospital is not so likely to be taken into consideration, especially if the proposal is the application of a new work shift schedule. On the other hand, Scenario 3, in which there are 4 ASSISTE Member for transportation of patients with the regular shift scheduling, has been considered to measure of the impact of a two units increment of the staff in charge of movement of patients. From the percentage variation of both metrics has been computed for all the scenarios, and as expected Scenarios 3, 4 and 7 presents the higher reductions. However, the graph previously analysed are obtained considering all patients. It is interesting to see for different patient classifications introduced in the model which scenario should be considered in order to minimise the Total Wait Times or the Average Length of Stay. Except for No Problem and for Other Less Urgent Patient which do not present any variations in the different scenarios, 200 replications for each scenarios have been run, values for different patient classifications are reported in

	Urgent	Less Urgent	Elective	Other Urgent
Scenario 1	-	-	-	-
Scenario 2	-2,3%	-7,1%	-4,0%	-18,7%
Scenario 3	5,4%	10,7%	-3,4%	-0,4%
Scenario 4	5,3%	-15,0%	-4,0%	7,8%
Scenario 5	-12,2%	-3,1%	-1,5%	-33,1%
Scenario 6	0,8%	2,3%	-4,2%	-29,1%
Scenario 7	5,3%	-15,0%	-4,8%	7,8%
Scenario 8	0,8%	2,3%	-4,2%	-29,1%

Figure 51 Percentage Variation of Average Length of Stay per each patient classification

and *Error! Reference source not found.*.

	Urgent	Less Urgent	Elective	Other Urgent
Scenario 1	-	-	-	-
Scenario 2	-2,3%	-7,1%	-4,0%	-18,7%
Scenario 3	5,4%	10,7%	-3,4%	-0,4%
Scenario 4	5,3%	-15,0%	-4,0%	7,8%
Scenario 5	-12,2%	-3,1%	-1,5%	-33,1%
Scenario 6	0,8%	2,3%	-4,2%	-29,1%
Scenario 7	5,3%	-15,0%	-4,8%	7,8%
Scenario 8	0,8%	2,3%	-4,2%	-29,1%

Figure 51 Percentage Variation of Average Length of Stay per each patient classification

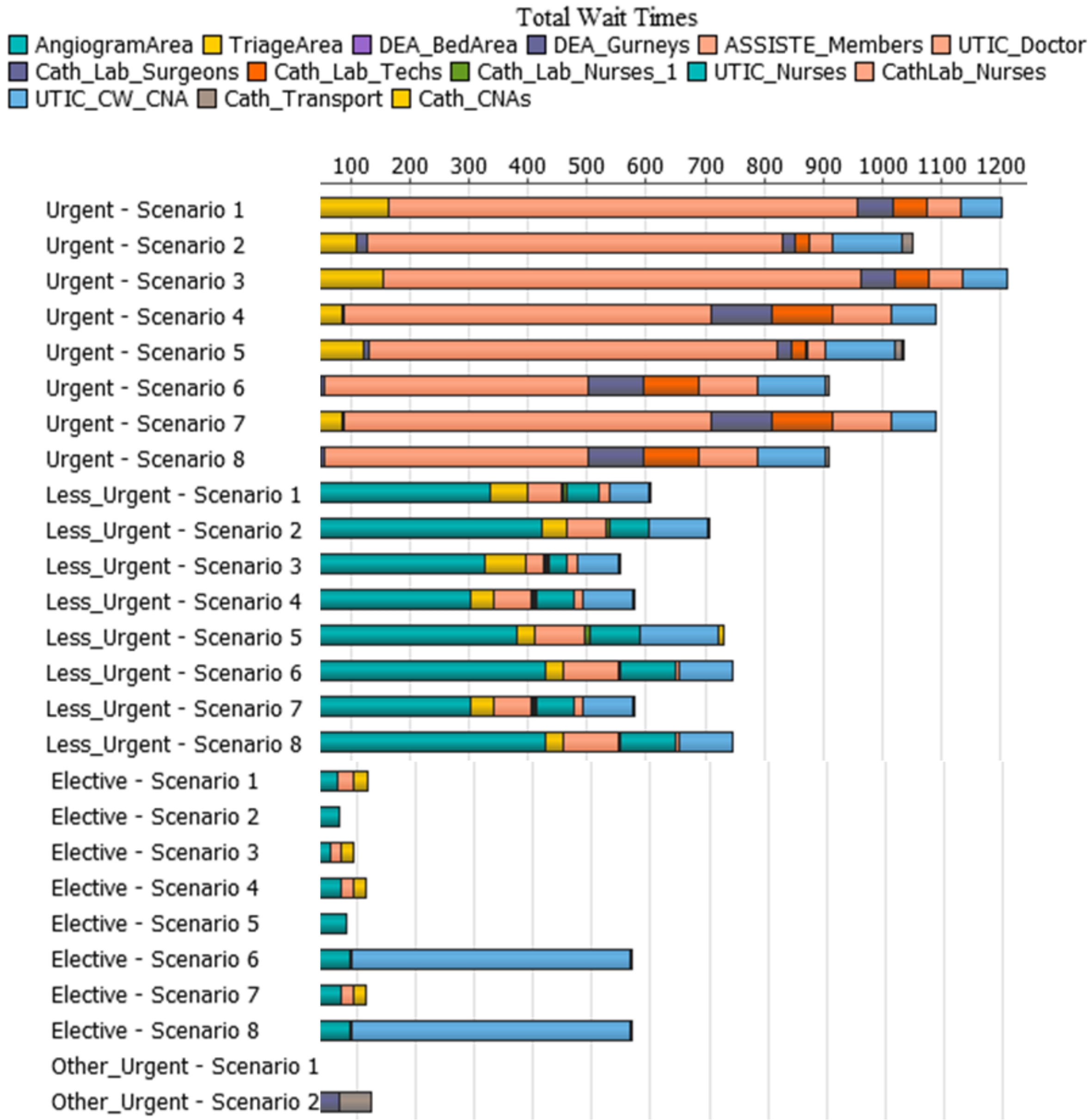


Figure 52 Total Wait Times detailed for different patient classifications

Comparing the average length of stay per each patient classification in all different scenarios tested, it has been possible to compute the expected variation in terms of percentage with respect to the scenario 1, in which no variable has been changed. Surprisingly, Scenarios 3, 4 and 7 which in the overall analysis considering all the patients were the best scenarios, when considering different classifications of patients, provide a reduction only for Less Urgent and Elective patients and mainly related to scenario 4 and 7. Instead Scenarios 2 and 5 provides the higher reductions especially for Urgent and Other Urgent Patients.

This result is importance for two main reasons:

1. First the patient classifications for which the highest reduction has been noticed are the most critical; Urgent patients in fact consist of the majority of patients treated within the Department (nearly 785 patients over the total, namely more than 66% of total patients entering in the Cath Lab).
2. Scenario 5 and especially Scenario 2 are the ones in which the number of Cath Lab Nurses per shift is the maximum possible, three rather than one of the minimum possible. This implies that the investments made by the Hospital for the construction of Electro-Physiology Lab would decreases for all different categories the average length of stay (from -2.3% for Urgent to -18.7% for Other Urgent) alone and if combined with a two units increment of the ASSISTE Members, it can lead also higher rates for Urgent and Other Urgent.

After due considerations, including the feasibility of the proposal improvement, the optimal scenario selected is Scenario 5, in which the number of Cath Lab Nurses per shift is 3 and the number of ASSISTE Members is 4 units, hence in which the ASSISTE Members group has been increased of two units, without modification and extension of their work schedule. From the application of these practices, the results expected are reported in the figure below, summarising the variations computed with respect to Scenario 1. From ***Figure 53*** Expected % Variations from application of Scenario 5 it is possible to see that changes are positively affecting all the categories, except for the Total Wait Time of Less Urgent patients which is expected to increase of slightly below 20%. Yet again, No Problem and

Other Less Urgent patients are not affected by any of the scenarios considered, because of the relatively small percentage of their arrival and in case of No Problem patients, because they have been added to the model only for avoiding oversimplifications in the model, but they do not interact with the system, except for the Triage and DEA staff.

	Urgent	Less Urgent	Elective	Other Urgent
Total Wait Time	-13,9%	19,9%	-29,6%	-10,8%
Average Length of Stay	-12,2%	-3,1%	-1,5%	-33,1%

Figure 53 Expected % Variations from application of Scenario 5

However, this is only part of the changes that the Department should implement and that is willing to implement. The construction of the Electro-Physiology Lab is certainly a crucial improvement that will provide substantial benefits for the Department and will make more efficient different processes and operations performed within the Department, but this is not the only measure that the Department should perform; in fact, to improve continuously patients care and maintain over time the level of efficiency achieved, it is important to effectively involve the entire staff in this lean transformation, changing their mindset and opening to a new way of organisation and standardisation.

Conclusions

The thesis aimed to explore unseen improvement opportunities within a public Italian Hospital, focusing particularly on some of the crucial procedures in the current healthcare context: cardiac catheterisation procedures. The application of lean principles and techniques guided the entire process, from the direct observation and initial interviews to an initial mapping of the Cardiac Catheterisation process for different categories of patients interacting within the Department, aimed to spot and identify all potential source of errors, delays and inefficiencies embedded in the different steps constituting the process. The Chief Doctor of the Cardiology Department, Dr. Massimo Giammaria, was very concerned about the lack of standardisation and measurement systems in the Department, which therefore was the starting point of this analysis. Part of the criticalities emerged during the analysis were related to repetition of manual and electronic tasks, miscommunication or not effective communications, transportation and delays, which are extremely common when dealing with healthcare environment. Then evaluating available data and deriving estimations for unknown values, it was possible to test different scenarios and suggest the more efficient. The proposed measure evaluates in part the effectiveness of some structural investment currently being performed within the Department and a change in the resources actually deployed for one of the most critical tasks, patient's transportation. This scheme is surely more effective in the simulation, because of the assumptions and simplification made, but it is expected to have a positive impact also in the reality, especially thanks to its feasibility. Nevertheless, this is only part of the measure that can be implemented when considering a Cardiology Department. One of the main limitations of this work is related to the limited time study conducted within the Department: for bureaucratic reasons it was not possible to effectively measure timing for different activities and processes described; hence the next step should involve a long-term time and data collection aimed at including any possible variability in patients' arrival and in activities duration over a longer timeframe. Moreover, a future continuation in this transformation may relate to an extension of the process mapping to all the different activities and operations performed within the Department, not only to Cardiac Catheterisation ones, to have a complete and wider view of the

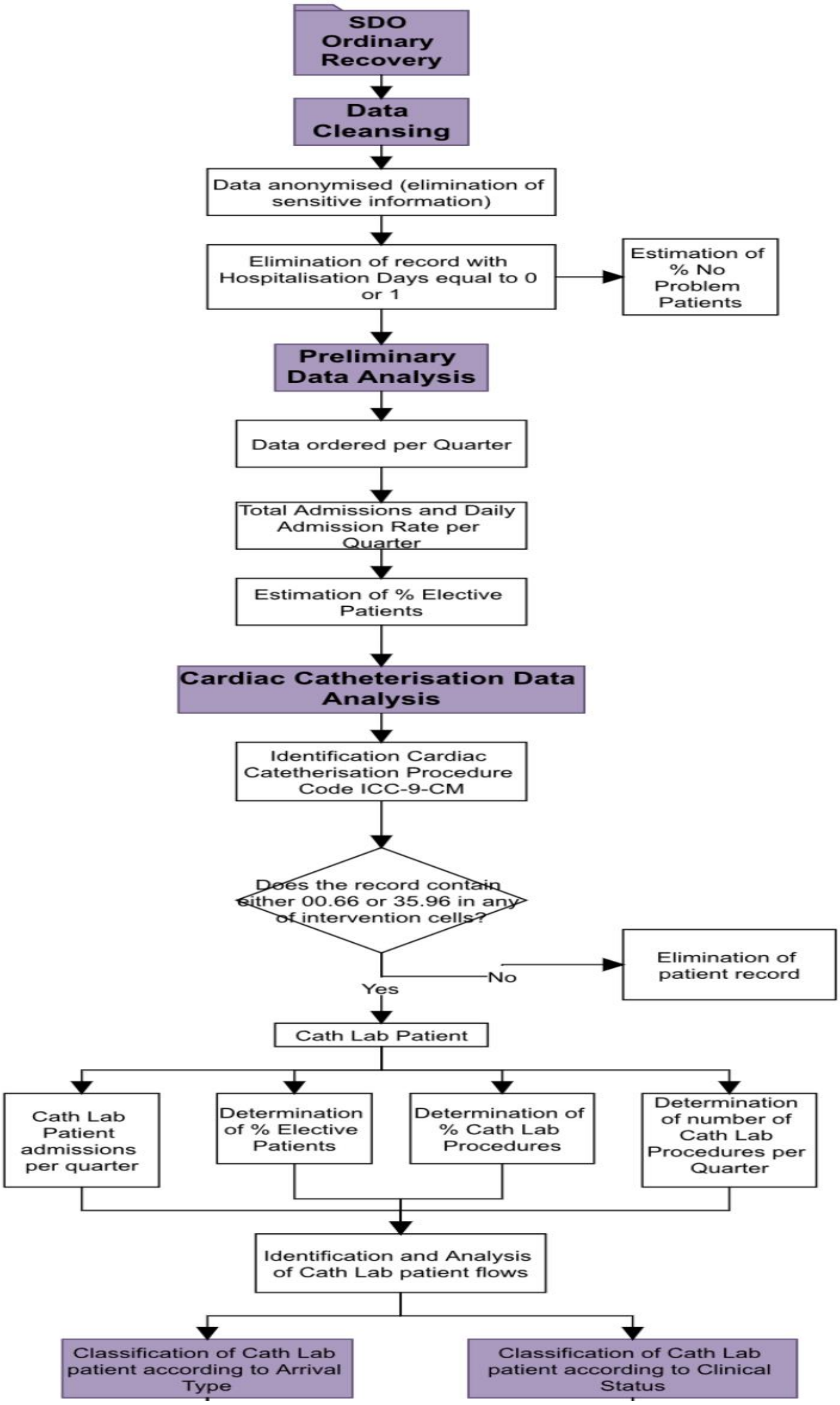
Department, reducing part of the simplification introduced in the current model. It should be considered that this is just a first step and that any other improvement will be only possible after a constant effort from the Department staff in understanding values and beliefs behind this transformation and their direct involvement.

The work showed that systematic application of systems and industrial techniques, as for instance Activity Diagrams or Cause and Effect Diagram, are powerful tool in the determination of critical points within the processes and can help management of the Department in achieving higher efficiency.

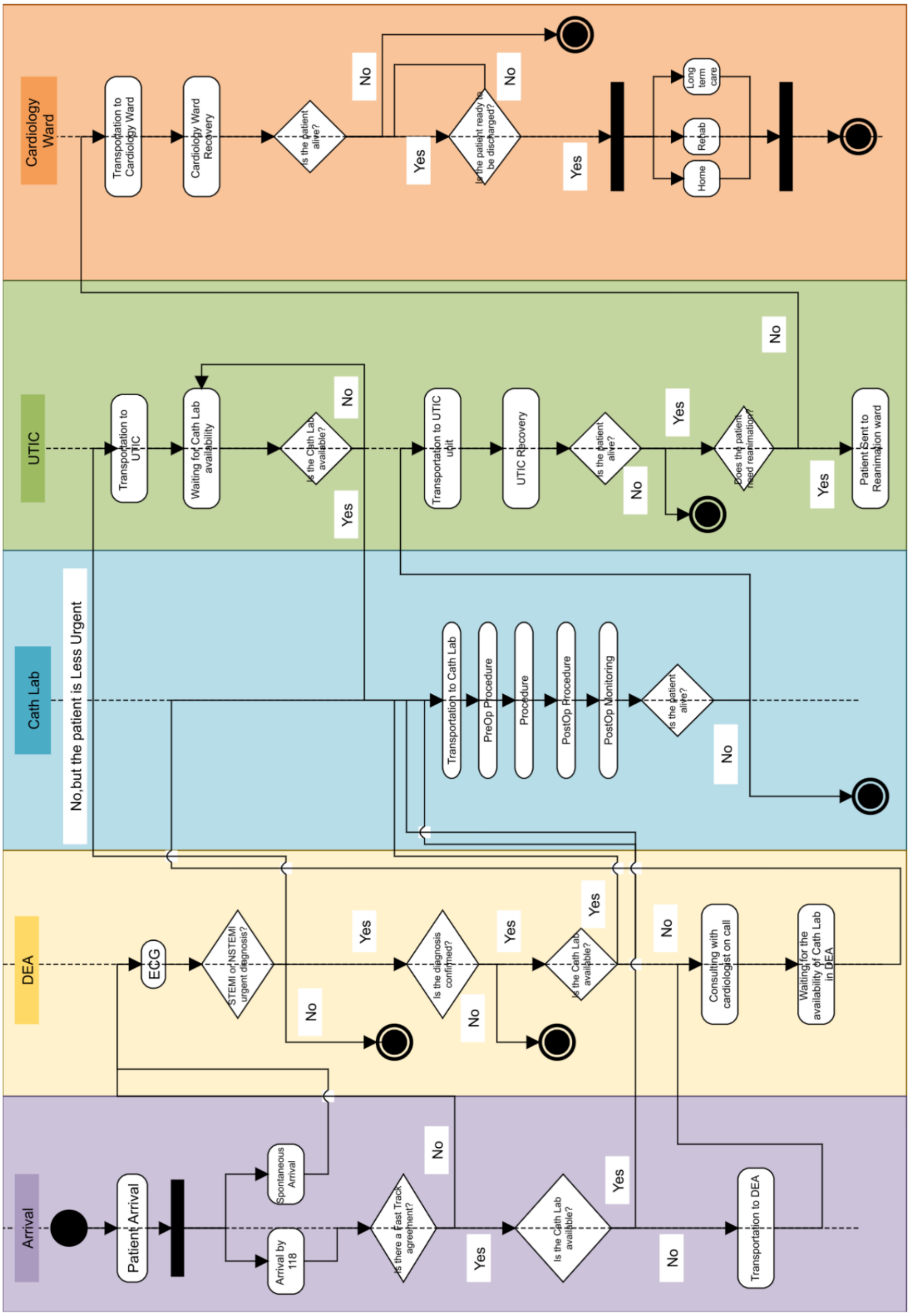
It is important to consider that a hospital is not a manufacturing company, and also that extreme standardisation will not provide an effective improvement in terms of quality of care provided. Yet, un-wasted time is time which can be dedicated to the patient in order to provide the same service with higher quality and greater safety.

Attachments

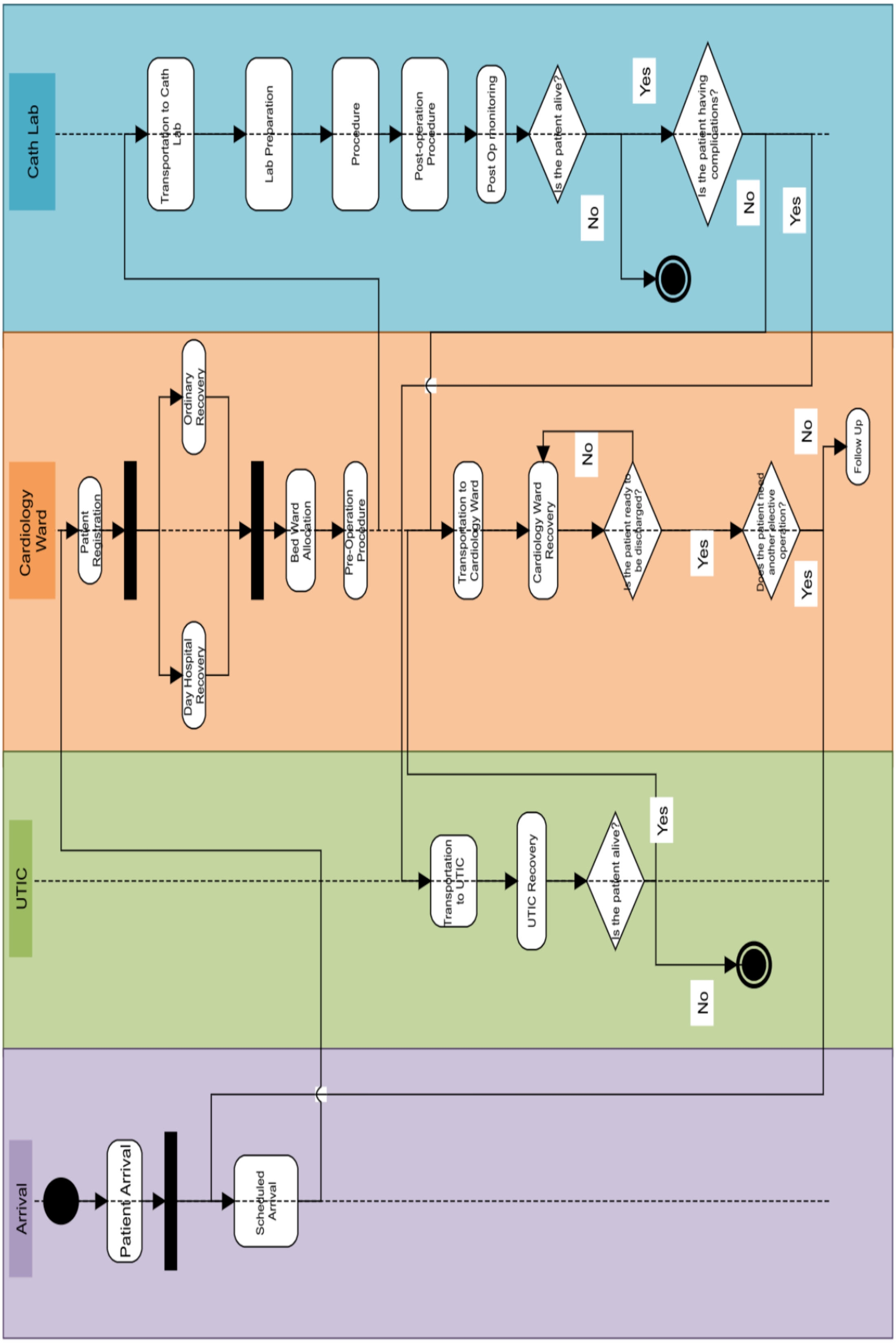
Attachment 1 Flowchart Data Analysis Process



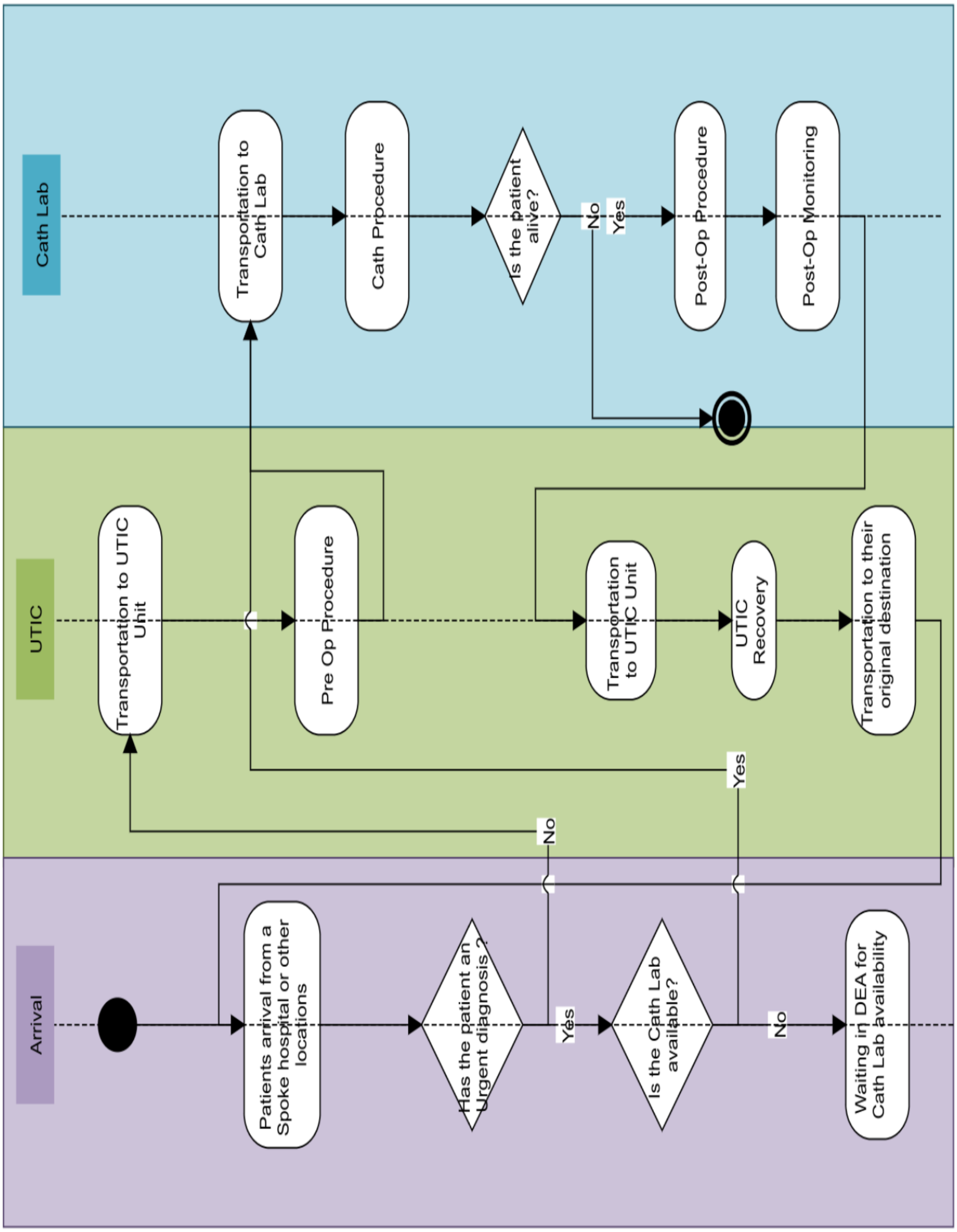
Attachment 2 Urgent Patient Activity Diagram



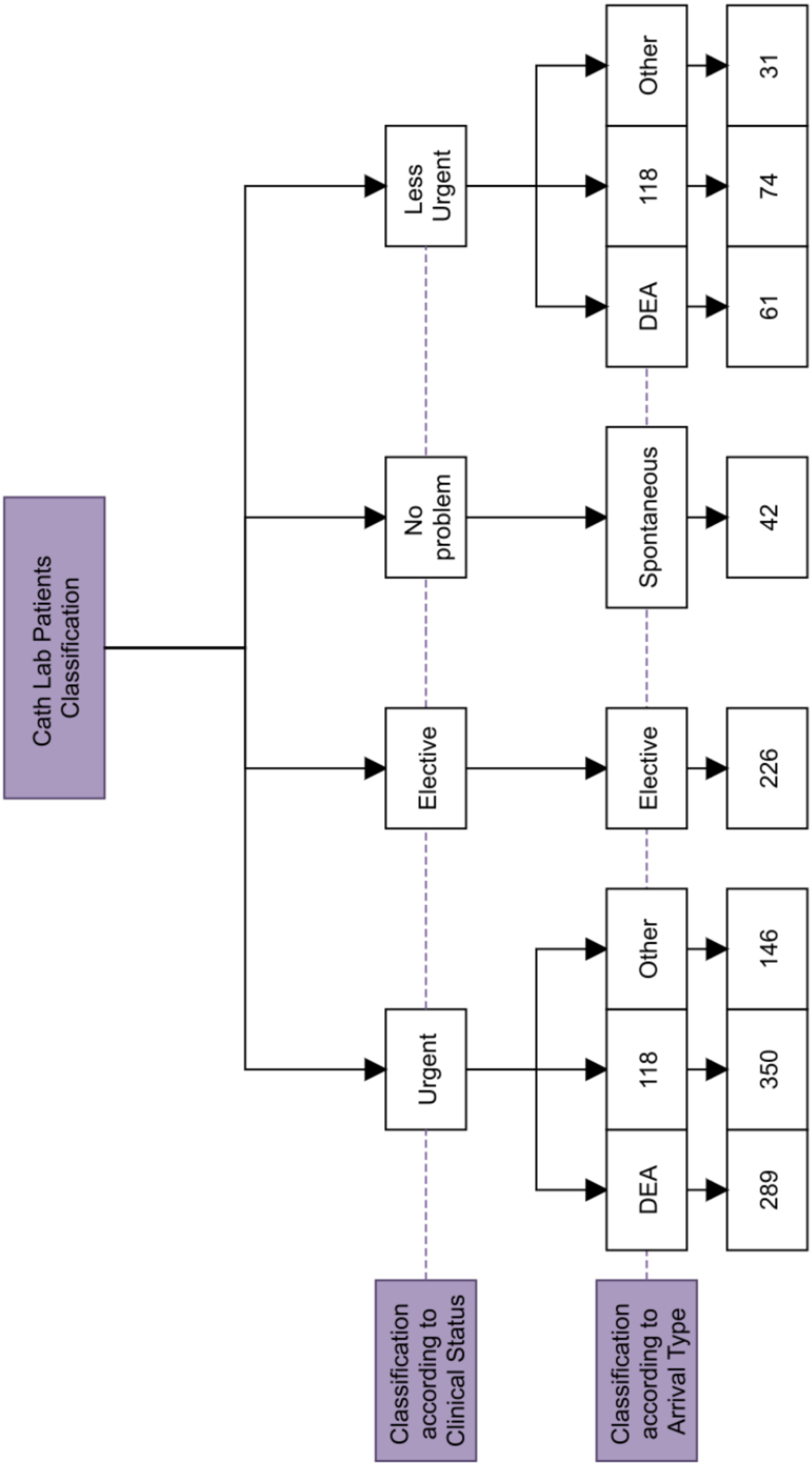
Attachment 3 Elective Patient Activity Diagram



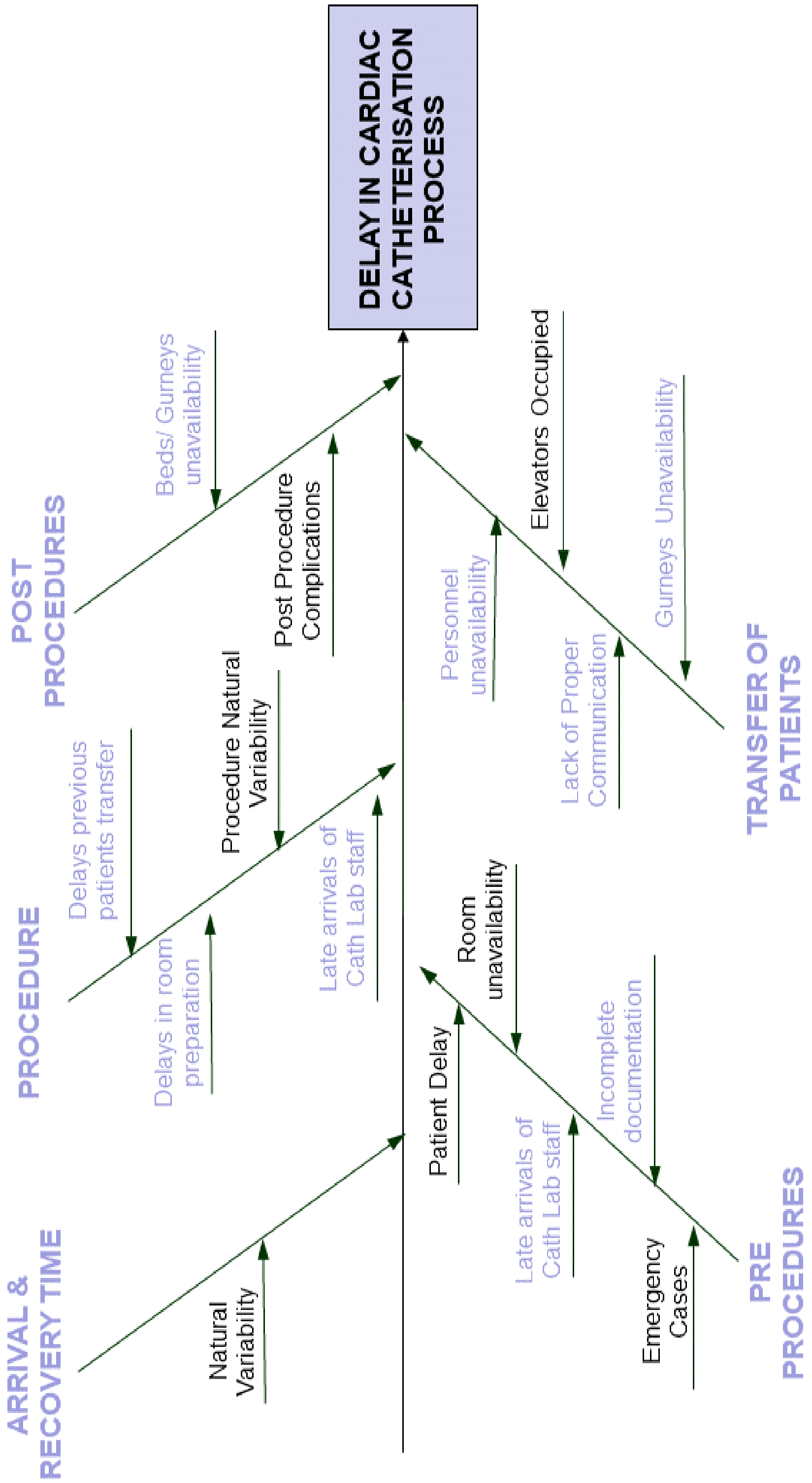
Attachment 4 Other Arrival Patient Activity Diagram



Attachment 5 Cath Lab Patients classification and assumed number of associated records



Attachment 6 Cause & Effect Diagram



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