ALMA MATER STUDIORUM – UNIVERSITÀ DI BOLOGNA
CESENA CAMPUS

Department of Computer Science and Engineering - DISI
Second-cycle Degree in Digital Transformation Management
Class: LM-91

The Role of Digital Twins for improving Sustainability in Healthcare: The IRST Case

Graduation thesis in
Software engineering

Supervisor
Prof. Alessandro Ricci

Co-Supervisor
Dott. Francesca Galardi

Candidate
Paolo Zanatto

4th Session
Academic Year 2022-2023

This thesis derives from the internship experience carried out at IRST in 2023, within a period in which the institute will profoundly evolve and where the complexity already present in current activities will further increase. From a condition in which the Pharmacy department produces therapies for 3 centres, the number of users to be supplied will triple through the Comprehensive Cancer Care and Research Network (CCCRN) project in collaboration with AUSL Romagna. Given the need to manage new and more complex processes, together with IRST's commitment to becoming more sustainable, the project in question has matured: improving decision-making processes in a sustainable perspective through data.

To this end, this thesis aims to demonstrate the validity of a Digital Twin (DT) approach. That has been used to drive the work of analysis of the therapy production process, examined as the focus of IRST's activities and of the new project with AUSL, defining the key information to be captured and providing a starting point for developing further studies aimed at extracting this information. In parallel, a proposal for a model of Digital Twins (based on the Web of Digital Twins concept) and an example demonstrating the value of the analysis phase is provided.

To achieve this objective, the internship activities focused on engaging in dialogue with domain experts as a point of reference for a description of the reality in its essential features for addressing certain needs. While the thesis will proceed with an in-depth examination of sustainability in the healthcare sector and the value provided by the Digital Twin, demonstrating whether this approach is strategic with IRST's challenges.

Contents

List of Figures

Chapter 1

Introduction

The first chapter has the role of introducing the drivers, concepts, and the context where this work originated. It aims to provide an overview of the context and needs of healthcare systems, then describing the approach adopted in this thesis. The last section presents the thesis, by discussing its structure and the objectives set. In addition, the presented concepts supply the foundations for the reasonings and the needs faced during this work.

1.1 Digital Transformation in IRST

This section serves as an exploration of the contextual backdrop wherein my activities during the internship transpired—looking at a wider view of the healthcare context and oncological cure, linking with the relevance that they have in sustainable terms.

IRST is a centre of excellence entirely dedicated to treatment, research and training in the field of oncology. This specific sector of medical services concerns various complexities that originate from the need to invest massively in research and experimentation paths, the huge costs that oncological treatment requires and the trend of our society. To provide some numbers: in 2015 in Italy oncology absorbed about one-third of the resources dedicated to the entire hospital pharmaceuticals sector, and precisely in Romagna over 25% of the pharmaceutical expenditure is made up of haematological drugs. In parallel, the annual growth rate of patients is 3% corresponding to an increase in costs of 15%. Then, over all these points, they have to face all the difficulties related to their nature: a big hospital with many stakeholders, that requires coordinating hundreds of people to provide the best service possible.

To address the challenges described, IRST and Ausl Romagna have launched a project for the overall improvement of the efficiency and effectiveness of oncology drug management. This is logically the centre of care, and enhancing its management and production is an excellent approach to the problems described. This project brings with it many benefits and just as many complexities that must be managed for the improvement to bear fruit. Above all, the drug production and supply processes.

Healthcare service providers are complex realities that have a central role in our society, as well they have in terms of sustainable impact. The dimension of expenses over the national GDP (Gross Domestic Product) is considerable (9% in Italy on 2022). The care service is intrinsically a service with a strong impact on the social dimension, and it is one of the main sectors affected by the socioeconomic crisis. On the other hand, the resource consumption is comparable with the other sectors known as energy-intensive, without considering that is the only sector that produces every type of waste.

From this description with related necessities appears critical to have an approach that permits monitoring and managing as best the managerial choices and considering the impacts. That is one of the reasons that makes oncology, and in the healthcare sector in general, one of the fields where technological evolution is most prominent, with Healthcare 4.0. Much investment and research have gone in this direction and demonstrated the high potential and space for implementing technological solutions.

1.2 Exploring Digital Twins for Innovation

IRST has demonstrated over the years to be an excellence centre also for its interest to be open to innovation. They are recognised for the constant activities in oncological research and experimentation in the territory of Romagna, supporting emerging or innovative technologies and the necessary infrastructure for the promotion and evaluation of research and assistance.

In compliance with this orientation for care, IRST aims to extend innovation to management procedures to address the challenges presented before. These can be identified by the highly complex relationships and dimensions involved, from which the management has to start to make decisions. The strategic approach chosen has been driving the decision by data and from this, the internships and thesis have originated. In detail, the work identified the Digital Twin approach as a valuable opportunity for its ability to represent reality in the significant features for extracting knowledge.

The most used application of this approach in Healthcare is for organs and body representation for improving the efficiency of cure. Here, the value provided by this thesis is extending the opportunities of Digital Twins for improving the decisions of management by supporting the critical information that allows them to operate as best in front of system complexities. To be more precise, the analysis has been developed on the concept of Web of Digital Twins for improving the management of the therapy production process.

1.3 Thesis Objective: Digital Twin for Improving Sustainability

This chapter will discuss the objectives of this thesis and the internship experience, briefly describing the reasoning behind achieving them. First of all, this work stems from IRST's need to address the challenges posed by the radical change they will have to face, seizing the opportunities for renewal provided by this evolution, and their desire to move in the direction of sustainability.

The objective is to demonstrate how a Digital Twin approach can be a key opportunity in addressing IRST's challenges regarding the CCCRN project and the criticalities of the therapy production process, oriented towards sustainable development, in line with IRST's values and objectives. To achieve this goal, it is aimed to carry out a detailed analysis of the therapy production process in all its steps, outlining the connections and relationships behind the valuable activities. This will be followed by a discussion of some of the criticalities observed by the domain experts, trying to bring out the real needs and key factors that would allow these to support these significant situations. Through these, we aim to demonstrate, using a model proposal, how a system based on Digital twins could represent a solution to address the criticalities in the production process within the IRST challenges and the institute's sustainable development process.

In support of the demonstration, the work discusses the key concepts of this thesis. First, we will proceed by defining the concept of sustainability and sustainable development, discussing its relevance in healthcare, bringing out the complexity required to support and implement these concepts in ordinary activities, and recalling some examples where digitalisation is a possible support to overcome this obstacle. Next, we aim to define the concept of the Digital Twin, bringing attention to the idea on which it is based and the value this approach provides. In conjunction, the concept of Web of Digital Twins, will also be presented, looking at whether this is a valid opportunity in the face of the complex challenges of sustainable development.

After that, the focus will be shifted to the IRST reality, of which the challenges of the CCCRN project will be studied, and in particular, those that the therapy production process will have to face, according to the meetings held in the Pharmacy environment. Here we will proceed with an analysis of the situations that emerged as critical, followed by a model proposal concerning the therapy production process, discussing how this can respond to the points of intervention that have arisen and allow improvements to be made in a vision of sustainable development. This investigation aims to be the real contribution of this work both in terms of value generated and as a demonstration for the development of solutions in this direction, as well as a starting point for concrete developments of a system based on the Digital Twin.At the end it will be tested the value of the analysis phase by a practical example based on a Machine Learning algorithm to address one of the cases considered, where it will be presented and its results discussed.

1.4 Thesis Structure

Accordingly, the remainder of this thesis is structured as follows. The first chapter discusses the IRST context (chapter 2) by providing an overview of the place where the internship was done describing the Pharmacy department and the upcoming CCCRN project. Thereafter, it is presented an in-depth discussion on sustainability and its meaning in the healthcare context, by discussing also how digitalisation can support sustainable development (chapter 3). This will be followed by a chapter on the presentation of the Digital Twin concept (chapter 4), its functionalities and potentials, the value proposition behind this approach, and finally the developments within the healthcare context, as Web of Digital Twins, will be presented. Afterwards, the contribution of the thesis begins, with the analysis of IRST's challenges (chapter 5), looking at the impacts of the CCCRN on the Pharmacy, and finally bringing attention to the therapy production process and its critical issues. The thesis proceeds with the description of the proposal of the model in all its elements (chapter 6), discussing how it addresses the observed criticalities, providing in the end a practical example for testing the value of the analysis phase, exploring one of the critical processes presented (chapter 7).
Finally, chapter 8 concludes this thesis by summarising its main contribution.

Chapter 2

The IRST Research and Care Centre

The following section aims to present the context where the internship was executed, by providing an overall description for understanding their mission, their activities and numbers, followed by the exploration of the ward and project of interest for the internship's work.

2.1 Context, mission and values

The Istituto Romagnolo per lo Studio dei Tumori "Dino Amadori" - IRST is an IRCCS (institution for hospitalisation and care of a scientific nature) devoted to oncology treatment, research, and education. IRST adopts the "population" organisational and managerial approach, promoting a centralised coordination of oncological functions and activities with its primary focus on meeting the needs of citizens, operating in accordance with the most accredited international experiences. Since March 2012, IRST has been officially registered as an institute for advanced therapies in medical oncology, hospitalisation, and scientific care (Istituto di Ricovero e Cura a Carattere Scientifico, or IRCCS).

IRST is fully integrated into the Health Service in the Emilia-Romagna Region as a provider of an important public service, since its nature as an investee company under public control. A coordinated governance of oncology based on the concepts of cooperation and collaboration between the network's nodes is promoted by IRST and the AUSL of the Romagna (as presentd later on). However, the capabilities of the individual centres and the accessibility of care for all residents are also encouraged.

The goal of the Istituto Romagnolo per lo Studio dei Tumori 'Dino Amadori' - IRST Srl IRCCS is to tighten the connection between treatment and research while fulfilling its role as a reference centre in oncology. It is aimed by ensuring the quality, uniqueness, innovation, and transferability of laboratory results into clinical practice. IRST adheres to the National Health System's tenets, which include universality, equity, appropriateness, continuity of care, participation, transparency, efficiency, effectiveness, quality, and cost-effectiveness, placing safety, respect for individuals, and a patient-centred approach at the centre of every action and project.

The IRST network is made up of several interlocutors:

- Patients, Family members, Citizens, Volunteers
- Regional Health Service, AUSL Romagna and other health service providers (ASL, AOSP, AOU, contracted hospitals, hospices)
- National Health Service, Scientific Hospitalization and Treatment Institutes (IRCCS) for oncology, Ministry of Health, Ministry of Education, University and Research
- National and international public and private partners, Universities, Local Authorities and Territorial Socio-Health Commission, Oncology and Health Associations
- Donors and Media

They belong to the group actors that are at the centre of IRST decision-making process: the stakeholders. IRST considers the strategic involvement of stakeholders and asset holders in the various levels of decision-making processes as an indispensable necessity to direct and improve the processes of planning and management. Their positioning is measured by a 5-level scale with increasing intensity of involvement:

1. Knowledge - stakeholders are involved in order to increase their knowledge and awareness.
2. Consultation - stakeholders are involved for the purpose of gathering their opinions, needs and feedback.
3. Cooperative design - stakeholders are involved in the design of services and activities tailored to the target audience.
4. Cooperative production - stakeholders are involved in the shared input of economic, instrumental and human resources crucial to the final outcome.
5. Cooperative management - stakeholders are involved in decision-making with shared responsibility and, consequently, also of the results obtained.

Figure 2.1: A descriptive map of IRST stakeholders (from [37]).

The circles around show the closeness to the organizational areas and the impact of the involvement. From the further one, that concerns the acknowledgement of the third party about IRST operations, to the nearest where the external actors participate in decision-making processes becoming also responsible of the actions undertaken. Out of this point, every of these level are considered relevant because the "furthest" provide the necessary knowledge for the "nearest".

2.2 Organization and operational numbers

The IRST initiative comes from a combination of public and private non-profit organisations. The structure birthed is a limited liability corporation (S.r.l.) with a majority of public capital: this non-profit organisation possesses the traits of a social enterprise, such as the duty to use revenues only to fund the institutional endeavours the mission envisions and the ban on profit distribution. In 2020 IRST was legally established as a publicly controlled private law company, where the business partners are the following. The public ones own the 74,62% combined in:

- Regione Emilia-Romagna 35,00%
- AUSL della Romagna 33,40%
- Università di Bologna 5,00%
- Comune di Meldola 1,22%

The private partners own the 25,38% split in:

- Istituto Oncologico Romagnolo 12,65%
- Fondazione Cassa dei Risparmi di Forlì 6,08%
- Fondazione Cassa di Risparmio di Ravenna 3,04%
- Fondazione Cassa di Risparmio di Imola 2,00%
- Fondazione Cassa di Risparmio di Cesena 1,08%
- Fondazione Cassa di Risparmio e Banca del Monte di Lugo 0,52%
- Fondazione Banca del Monte e Cassa di Risparmio di Faenza 0,01%

Approach to care Out of the legal structure, that can be important to understand the context and define some duties, the inner organization is the core of daily activities. The IRST model places the patient "at the centre" and, therefore, prefers an organization based on care pathways, and not on division into departments. Within the Department of Oncology and Hematology clinical and experimental, doctors are divided into Pathology Groups, operating units dedicated to a specific set of diseases. The Pathology Groups, in which multiple professionals collaborate (doctors, biologists, pharmacists, nurses, data managers), work to define diagnostic-therapeutic pathways, ensure optimal patient management, promote consistency, continuity, and coordination of the entire care process, increase the degree of patient involvement and satisfaction. Human resources play a vital role within an organization whose main purpose is to provide personal care and do research. In 2021, 498 professionals (full-time equivalent) worked in IRST, the majority of whom were researchers, nurses, and doctors equal to 26.5%, 22.5%, and 20.9% respectively—followed by laboratory technicians (14.3%), technicians and office workers (9.4%), and healthcare managers (6.4%).

Healthcare professionals flexibly use services and facilities, such as Ordinary Inpatient Care, Day Service and Outpatient Clinics, Instrumental Diagnostics, Bioscience Laboratory, and research platforms. To allow multi-professional evaluation by IRST specialists and AUSL Romagna, multidisciplinary pathways are in place for referral and continuity of care. In this way, it is possible to outline the global path of diagnosis and treatment of the patient in compliance with national and international guidelines.

Size Up to what is described in fig. 2.2, it is clear that IRST, as any healthcare service provider, is a complex structure. Here is not relevant to understand the components and the elements that allow this machine to work, but it is useful to understand briefly the dimensions of the service and patients involved. In 2021 the overall patients cured was 25063, with a growth rate of 9% which shows a recovery of volumes managed before the Covid-19 pandemic. And the related costs amount to about 93 million where 39% concerns the purchase of drugs and related assets, 34% are about human resources in a broad sense, and the remaining are related to maintenance, non-medical services, depreciation, utilities, and other sources. On the other side, the funding sources come, mainly, from the support of the region Emilia-Romagna. However, the dependence of the IRST budget on the Regional healthcare fund is limited to 69% of total revenues (which is reduced to a little more than 57%, if the mere reimbursement of Drugs is excluded) an aspect that confirms the ability of IRST to sustain itself without burdening the Emilia-Romagna healthcare system. The other sources come from research funding (16%), extra-regional service reimbursement (12,6%), and donation (2,2%). In general,

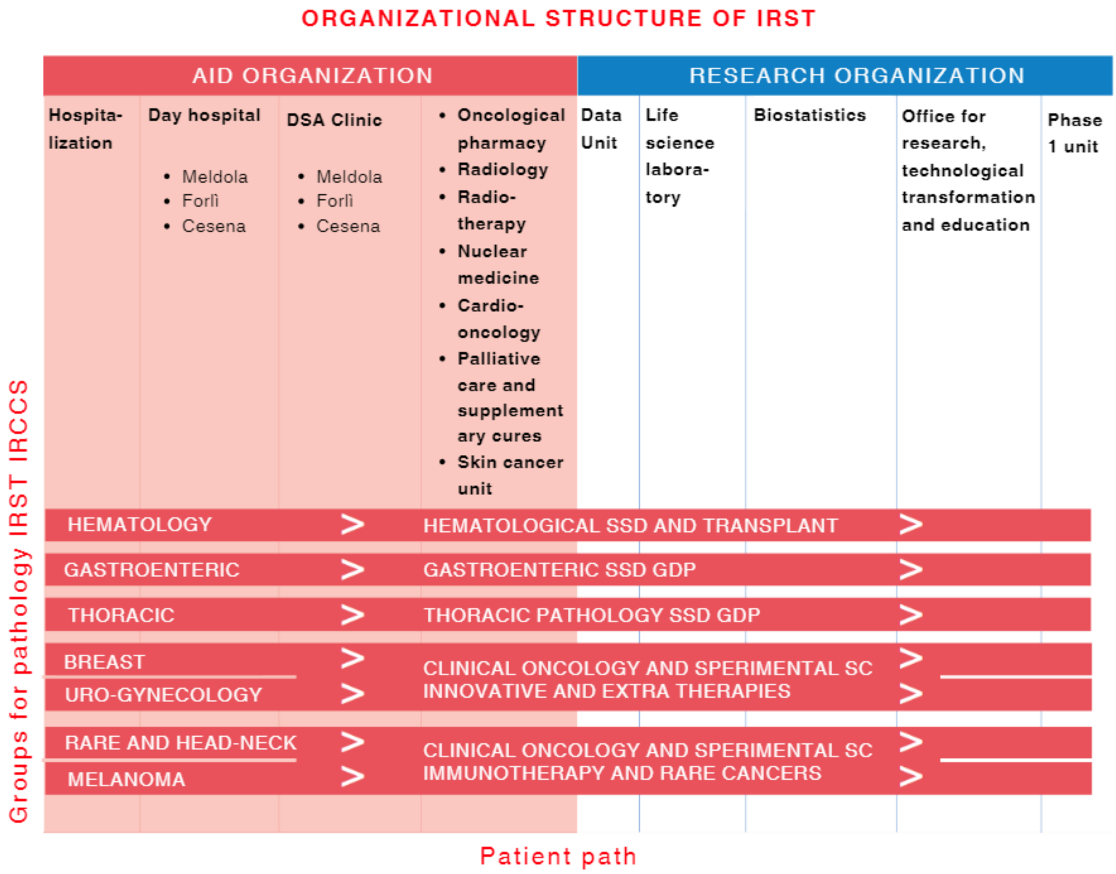

Figure 2.2: A descriptive map of IRST organizational structure (from [37]).

since IRCCS recognition in 2012, IRST has always achieved "sustainable growth," characterized by:

- Budget profits allocated to the Institute's independent research reserve (as of 2017);
- 7% average/year increase in revenues, supported in preponderant part by funding outside the regional healthcare fund;
- Steadily reducing debt and self-financed investments;
- Avoided costs for the Regional Health Service generated by not consuming drugs from practice clinical practice (thanks to the use of experimental drugs for about 5 million euros per year);
- Iimproved capital strength to guarantee the value of public holdings.

Environment care One last subject relevant to the work of the thesis concerns environmental safeguards. Since 2021, energy issues, especially due to geo-political emergencies and market fluctuations, have taken a prominent role. Actions taken in the area of energy efficiency and reduction of pollution produced by the company's activities have proven to be decisive not only from an environmental point of view but also from an economic perspective and in contributing to overall well-being. In full compliance with national and EU regulations, in addition to procedures to prevent potential crimes on the subject, IRST promotes the evaluation and constant monitoring of the environmental impact of the facilities and activities carried out (treatment, diagnostics, research).

Up to now, the measurement systems are limited to the verification of consumptions of electric energy and gas. Considering the couple of years 2021 - 2022 the electricity acquired (in kWh) and the gas used (m3) have been reduced to 33,47% and 61,44% respectively. This is surely related to the increase in energy costs, which caused to pay more the electricity in 2022 even with the reduction. But it is caused also by the measures took in action by IRST:

- Substitution of the entire led structure and centralized electronic supervision (completed in 2021).
- Insertion of central electricity meters (completed in 2021);
- Installation of 80 kW photovoltaic system for electricity generation (started from July 2022).
- Start-up of the 430 kW co-generation plant serving the main bodies of IRST and the upcoming building of CCC.

These measures are the starting point for the future, where IRST wants to invest more in environmental policies, to be more sustainable and save costs that can be invested in the other goals set.

2.3 Pharmacy

I executed my internship inside the Healthcare direction unit, in collaboration with the responsible for logistics operations. So, one of the focuses has been on drug production (in charge of Pharmacy) and warehouse management operations. The warehouse activities are similar to the common ones (out of healthcare organization) but the therapy preparation requires a quick explanation.

The Pharmacy is a highly specialized department, that reports to the Healthcare direction and has specific laboratories for providing the personalized and safe preparation of drugs that make up cancer therapies for the IRST sites (Meldola, Forlì, Cesena) and all therapies with oncology drugs also for the Non-Oncology Operating Units of the Forlì and Cesena hospitals. The Pharmacy is affiliated with the Radiopharmacy Laboratories, within which the activities of preparation and quality control of extemporaneous radiopharmaceutical preparations are carried out. The department is a reference for the Regional Network of Oncology Pharmacies and participates in the activities of the Romagna Vast Area Pharmacy Commission and the Regional Oncology Drugs Commission. The Pharmacy also develops and participates in research and clinical trial projects, designs and collaborates in information programs on the good use of oncology drugs aimed at the patients themselves.

The Pharmacy is equipped with automated staging laboratories (two robots and a system to support the manual production) that contribute to the reduction of risks during staging for both the patient and the operator and ensure the traceability of the preparation. The percentage of automation in 2021 (percentage ratio of automated drugs to automatables) was 99 percent (98% in 2020). Oncology set-ups in 2021 were 53,835 (9% more than in 2020) while the ancillary drugs delivered with oncology therapy were 86,274.

Construction of the Oncology Pharmacy of Romagna (section 2.4) is underway, preparing all oncology drugs in Romagna. As part of the implementation of this new project, the following signs of progress are expected:

- Development of unit dose in the acquisition of robotic technologies;
- Implementation of an additional robotic technologies for drug preparation, bringing the equipment to 3 units;
- Uniformity of treatments within the Romagna oncology network thanks to the standardization of therapeutic schemes and ancillary drugs.

The next section describes the project mentioned and the relevant aspects of the internship activities.

2.4 Comprehensive Cancer Care and Research Network (CCCRN)

In recent years the operations and the mission of the organisations engaged increased through shared governance of the primary research assets: AUSL Romagna and IRST "Dino Amadori" IRCCS formed the Comprehensive Cancer Care and Research Network (CCCRN) initiative in Romagna. It is an inter-agency programme for the Unified Management of the Oncology Drug Preparation Pathway that aims to maximize the activities and mission of the entities involved through shared governance of key research assets, through the homogenisation and centralisation of the oncology drug preparation pathway.

The project's crucial component was the establishment of a network that would allow the centres to collaborate and work together throughout the region to provide patients with a fair, superior, and uniform response. This network would only handle activities and experiments that were highly complex, in line with the unique missions of each of the individual structures.

The vision of this project is to realise a safe, sustainable and efficient working environment for patients and operators. These are the principles that drive the decisions, and the strategic goals, which are the following:

- Improve safety and quality of therapies, as well as increase operational efficiency (automation, waste reduction, etc.).
- Homogeneity of access, care pathways, and harmonization of therapies in Romagna.
- Unified oncology drug governance with progressive reduction of unwarranted variations between territories (availability of BI tools on consumption and per capita costs).

Based on them, the goal has been to develop a highly technological structure and organization, to centralize the services, reduce the costs and increase the efficacy and efficiency of the production line. This new building is under construction (with the expected conclusion on half of 2024) and is at Meldola, near to IRST. It is shown in the fig. 2.3 and it is called here 'CCC' (Centralized Compounding Centre). Here, there will be transferred three activities already present and active in IRST at the Institute:

- The Oncology Pharmacy Laboratory.

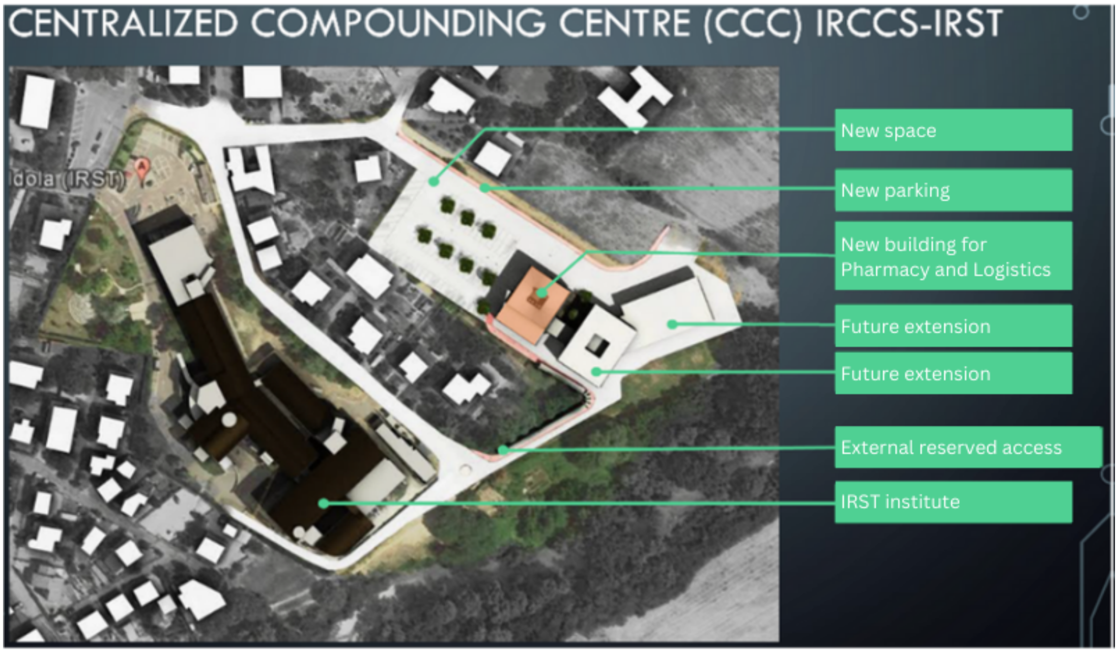

Figure 2.3: The future aspect of Meldola when CCCRN will be completed.

- The new IRST radiopharmacy located on the second floor of the Institute in the Department of Medicine Radiometabolic Nuclear,
- The IRST pharmaceutical warehouse

This evolution is translated concretely into the overall management of the Oncology Drug Preparation Pathway entrusted to IRST IRCCS, which will be responsible for:

- Centralisation of set-up activities.
- Unified management of side effects.
- Distribution of the oral oncology drugs.
- Centralised management of prescriptive appropriateness.
- Definition and transversal governance of the expenditure budget.

The project represents the first step towards the establishment of the oncohaematology network, which is one of the IRST's major cooperation objectives.

The improvements required to manage the new volumes of workload will also be at the operational level through the introduction of a new robot for therapy production and 2 new devices for the management of drugs in the warehouse. These will work by producing the unitary doses of drugs and autonomous provision of them to optimize their management and increase strongly the traceability of drugs.

To correctly delineate the activities and organizational and management arrangements of the logistics process and supply chain, that is the system of organizations, people, activities, information, and resources involved in the process act of providing a service from supplier to customer; the current process has been analysed compared with the future process, outlining the steps to be taken for future design. This work has been used for the comprehension of the context, a good point for addressing the issues in the proper way.

This work is not reported here, differently to some differences, complexities and important improvements that got in touch with the areas touched during the experience. This part is discussed in the following chapter. This description is the starting point for the analysis (chapter 5) and the contribution of this internship.

Chapter conclusion This section concludes the introductory chapter of this thesis. The objectives of the internships and thesis have been presented, jointly with an exposition of the context where it has been executed and the project related (CCCRN).

Given this description, now the attention is moved on the the key concepts for the development of the work: Sustainability first and Digital Twin then. The IRST description can provide a good framework where to place the reasonings about sustainability in healthcare and introduce a relevant argument that will be discussed in the following: the complexity and the necessity to face it.

Chapter 3

Sustainability: dimensions and complexities

In the description of IRST emerged their attention to the environment, translated into the evaluation and monitoring of the environmental impact of activities and facilities. Considering this aspect as relevant to 2 other dimensions: the economic, for the costs, and the social, taking into consideration the responsibility on the overall well-being.

Here the focus is placed on all these dimensions, enclosing them into the concept of sustainability, and exploring its aspect in the healthcare sector. In addition, a relevant concept for the overall discussion is introduced: the complexity of tracing relationships among distinct elements, which will be recalled many times in the following chapters.

This section is organized as follows: an initial introduction to the concepts of sustainability and its origin (section 3.1), followed by a description about the relevance of healthcare in all the dimensions (section 3.2) discussing in detail each of them (section 3.2.1, section 3.2.2 and section 3.2.3). A final section is focused on the exploration of possible measures for sustainability in healthcare (section 3.3), discussing about a proposal and the role that digitalisation may have on that (section 3.3.1).

3.1 Concept of Sustainability

This chapter aims to provide sufficient knowledge to understand what sustainability is and what it means inside healthcare organizations. It is a wide topic and the reasonings have been supported by the literature about this, which can be further explored for going into deep. So, given its complexity and its extension, the goal is not to create a type of landmark for the field, but instead to provide a possible approach to the question that requires to be understood, explored and adapted for each single case. It is related within the context since, after this chapter, it is supposed to be easier to understand why and how a Digital twin can support IRST operations to reach higher sustainability.

First, it is critical to start with the concept of sustainability: it has become strongly discussed in recent years and many definitions have been given about it, mostly confusing and overlapping its concept with 'sustainable development' or moving its meaning to one of the fields, without taking in consideration all the other facets. Below it is described the concept of sustainability in the useful terms for the object of this thesis, without trying to give a final definition, and it is distinguished from sustainable development, which is the starting point in the discussion.

The origin One of the main contributions was given by the Report "Our Common Future" of the World Commission on Environment and Development in 1987 [1]. It has been the starting point for any reasonings and publications on the subject because it has been one of the first publications by a worldwide organization and it is rich in many relevant points for any further consideration.

> "*Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.*"

This is known as the 'Brundtland definition' and it is one of the main interpretations that has been given to sustainable development, focusing on the evolution rather than strategies to maintain a current condition. The document treated the topic from a global perspective, involving all the philosophical and ethical reasonings necessary to address the question, but out of the interest of the project. Thus two of the concepts discussed are considered useful for this case. The first one is about the elements that compose the sustainable development. Gro Harlem Brundtland in the introduction of the report discussed the challenges that our society has to face, and he stated:

> *"What is needed now is a new era of economic growth - growth that is forceful and at the same time socially and environmentally sustainable."*

The goal of that sentence was on economic growth, but it has been put at the same level of social and environmental development. As 3 flows that must proceed and evolve together. The second aspect concerns the relationships between them, or better, the existence of an infinite number of relationships between the elements that belong to these 3 macro-areas, and in general inside an ecosystem.

It is reinforced later in the same document [1] when the World Commission on Environment and Development stated:

> *"First, environmental stresses are linked one to another (. . .) Second, environmental stresses and patterns of economic development are linked one to another. (..) Third, environmental and economic problems are linked to many social and political factors."*

Additionally, about, the document proceeded with:

> *"Such links mean that several different problems must be tackled simultaneously. (. . .) Thus, economics and ecology must be completely integrated in decision making and lawmaking processes not just to protect the environment, but also to protect and promote development. Economy is not just about the production of wealth, and ecology is not just about the protection of nature; they are both equally relevant for improving the lot of humankind. (. . .) Hence new approaches must involve programmes of social development (. . .)"*

These three facets are strictly related when talking about development since an event typically close to one of them has a big impact on the others. Differently, the consideration of their connections is not worldwide defined. Purvis et. al discussed it in "Three pillars of sustainability: in search of conceptual origins" (2017) [28] and they concluded that are many opinions out of the one of UN. Some consider the parts as distinct where any interaction is a trade-off between the positive or negative impact on the object considered. Instead, other researchers approach the question as a system, where the reinforcement on one side is also an empowerment for the others. For this paper, it has been used the second idea as a way to look at these relationships. But, out of this distinction, Purvis et. Al closed the work by enlightening on the real issue behind the question: there is the necessity to critically analyse the model we embrace for understanding the effects of our systems. This should be the first step in order to find a way to develop sustainably.

But, what does it mean sustainably? Which the concept of Sustainable development?

Sustainable development Johnston et. Al in "Reclaiming the Definition of Sustainability" (2007) provides support by starting from the dictionary definition of 'sustainable', which is intended as the ability of action or activity to be sustained over time ([33]). It takes a different meaning in each context where it is considered and it depends on the limits of each. They stress on considering the time dimension for this definition because it depends on the domain of discussion. E.g. Environmental sustainability is defined as sustainable if respects the condition over a long period, wider than human life span or a profit cycle for a corporation. A certain activity is environmentally sustainable if it does not damage the environment over decades or centuries; and another activity is sustainable for a firm if the investment can be recovered in 5 years, for instance. The sustainability concept must involve a temporal scale.

From this idea, Johnston et. Al extends the definition of development as the progressive evolution compliant with certain sustainable conditions that allow to proceed in that process ([33]). In each context, the point to deep is understanding the conditions to be respected to be defined as sustainable, which have to be used for building a framework to use for driving any activity and designing the daily operations.

Talking about the framework, the most known example is the UN Sustainable Development Goals and targets [25]. It can be defined as a global action plan adopted by the United Nations in 2015, which sets 17 goals and sustainable development objectives (SDGs) aimed at addressing global challenges, improving human well-being, protecting the planet, and ensuring prosperity for all by 2030. It is a comprehensive framework that promotes sustainable development in various aspects, including the economic, social, and environmental dimensions. This Agenda underscores the importance of an integrated approach to promote development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Basically, this document redesigned the parameters for measuring the progress of development across multiple dimensions, as well as the responsibilities of corporations and citizens. It serves as a guide to steer policies, actions, and global efforts toward a more sustainable and inclusive future, where the pattern of development does not put pressure on the balance of the ecosystem and society. It is the biggest framework example about sustainability and it has been mentioned for understanding the role and potentialities of this support, and over the elaborate, the SDGs will be recalled about discussing the impact of actions. One of the main discussions about the UN SDGs is the way in which they are considered, or better the relevance of the relationships between them. An event regarding a certain dimension is not strictly related only to this one, instead has an impact on the others which in turn will affect many others. The conclusion is that a change on a certain side impacts all the others, exactly at the economic, social and ecological levels.

In the Figure 3.1 it is well described how inter-twined the UN SDGs are and it is the point: everything is connected and working sustainably on a certain level implies the consideration of other dimensions and impacts. It is the core of

Figure 3.1: A screen of Sustain2030, a German project for addressing the complexity of sustainability ([38]).

sustainable development.

About that, a non-profit organization has developed a framework fit for the SDGs. It is called Inner Development Goals [16] and they investigate, gather, and disseminate science-based abilities and attributes that support leading meaningful, sustainable, and fruitful lives. Since the UN SDGs cover a really wide field including far needs and values, and our society lacks in managing these complex challenges and environments: they realized the Inner development goals framework, that groups in 5 dimensions the 23 skills and qualities defined as "transformational for Sustainable Development", to learn and follow for a proper individual and organizational evolution in order to reach the UN goals. This project is relevant to be considered because it involves many useful concepts to consider in any design phase that aims to reach sustainable development.

The following section focuses on the meaning of sustainability in the healthcare sector, by giving shape to some economic, social and environmental examples that help to understand the wide impact of the sector and the complexity of reaching sustainable conditions.

3.2 Sustainability in Healthcare

Here the goal is exploring the meaning that sustainability has in healthcare sector. All the reasonings below starts from the concepts described in the previous section, from the real meaning of sustainability to its 3 dimensions.

To deal with this topic, a strong reference is made to the work done by Rattan and Joshi in "Sustainability indicators in public healthcare: a factor analysis approach" [29]. They started by discussing the evolution of the value concept in healthcare over time, as a possible way to follow for exploring the sustainable development in healthcare. Since the 1990s, the notion of value has evolved from being solely economic to include nonfinancial indicators of the healthcare system efficiency, like patient satisfaction and service quality, which are employed as part of management control and reported with the means used (e.g. balanced scorecard). Value-based healthcare expands on the efficiency focus by giving patients' needs and experiences precedence above supply-driven expectations and volume/-cost considerations. This approach is based on the idea that improving value in that sense will benefit the stakeholders (providers, payers, suppliers, and patients) while bolstering the healthcare system's financial viability. Broadening the actors considered is the power of this approach but keeping the consideration on the economical dimension is its main limitation in the sustainable reasonings. Rattan et Al [29] argued the system described by Porter and Teisberg [27], defining the lens of value-based approach in healthcare concerning the economic dimension as too strict, that put the attention only on the economic and individual impacts instead on a wider field, including the connections with other sustainability measures, as the UN SDGs. So, this evolution has been an important improvement for the healthcare system, but it requires an upgrade. This should involve the other 2 dimensions and all the relationships among them.

Another big support for this topic is given by Mehra and Sharma in "Measure for sustainability in healthcare" [22]. They debated about the impact of environmental quality on public health, and vice versa the ecosystem is greatly impacted by the resources used and the numbers managed by the healthcare systems. It is possible to add the impact on public health by social and economic dynamics, which would reinforce the concept. But the point is that sustainability and healthcare are closely intertwined, especially if it involves the inter-relations between factors. More specifically, sustainability in healthcare is a multidisciplinary topic that touches on operations management, medical science, and sustainability in general. These macro-areas involve a really wide range of activities and, as an example, the improvement in that direction, up to now, has brought to the adoption of integrated healthcare facility design, the decrease and effective management of medical waste, the implementation of circular practises, and sustainable procurement. The relevance of reasoning in this field comes from the dimension and the impact of the healthcare system on society in economic, social and environmental terms. The authors in [22] quoted a study of [9] that discussed the size in percentage over the national Gross Domestic Product (GDP), and it is notable as well as the impact over all the dimensions, directly or indirectly.

To deepen this topic, below are explored the 3 dimensions in the healthcare sector by discussing the impact of operations and the margin for improvements. Below are not listed all the impacting sources or the solutions for them, since this elaborate is not designed to be a guide, but it shows the correlation that these dimensions may have on the others, in order to give a first idea to detect independently the effects in each

3.2.1 Economic dimension

Mehra and Sharma in [22] defined the economic dimension of sustainability as:

> *"Economic sustainability refers to practices that support long-term economic growth without compromising other dimensions of sustainability. The economic aspect covers strategies that promote cost savings, profits, research, and development."*

The operations included in this definition are various and probably the economic side is the most developed of the three, since it has been the main focus of the for-profit business for decades and the tactics birthed on that field are many. The economic impact does not require to be explained: any operation has a cost, and the service of cure is expensive. Taking as an example the IRST operations of 2022 (from the related report [37]), the overall costs (around 75%) were derived mainly from medicines with related goods and human resources. The other costs are split into maintenance, depreciation, extra services (no health ones), extra health services, utilities and other expenses. Surely it is not a completely valid example for all the systems since the IRST is focused on researching and fighting cancer, which is a different focus and consequently brings different expenses. But it is correct to presume that these are some cost sources and the biggest part of them is due to human resources and products. So, economically speaking, these should be the two aspects to consider first for any reasoning. It is relevant to state that, since the funds are the mean used to improve the other dimensions, this information will be useful also on the other levels.

Proceeding on the economic side, many other considerations can be made: about the current condition, future trends, the impact of political decisions or possible events, as the ones done by Borgonovi et. Al [5] in the chapter 2.1. Out of external factors and costs related, in fact, the service depends by the internal decisions derived from the condition presented. In the paper just mentioned, quoting [11], the authors stated:

> *"(. . .) policy decisions about the allocation of available financial resources may prioritize current basic levels of care, overlooking the need for investing in innovative technologies, organizational change, and advanced infrastructures; however, missing innovation and change*

> *are expected to generate in the future increased costs for health services' provision. (...)"*

Talking about the possible improvements, any reasoning would start from the analysis of the affecting factors for defining how they can be improved under the economic impact. Making a list would be infeasible (for the length and for the little possibility to be complete) and useless since would not provide any support, instead can be helpful to explain some cases of interconnected elements. A good example of innovation that impacts on costs for health services provision is done by the 'Integrated care'. The authors of [17] presented this approach clearly, by describing that integration at various levels of care could impact the entire service and the costs to support the system. For instance, having a disconnected system would bring to having patients to lost in search of the service that they need, which means a delay in service provision, with a reduction of the quality and consequently the impact of the cure. It happens because, following an example from [18] quoted by Rattan in [29], the waiting time for patients is not only a measure of the efficiency of service performance (as may be in different contexts, as inside a warehouse with boxes), since the delay in receiving treatment can impact the quality of life of the patient, that may impact on the real effectiveness of the treatment at the moment in which it is administered. It is a question of investments that impact on the social dimension (without considering all the environmental expenses), that bring in the end at a reduction of service cost-effectiveness.

Another example can be the one cited by [29] concerns the costs related to wellness and health promotion. Adopting prevention is another really well-known approach that can strongly reduce the costs for the healthcare systems, and for this reason, this will become part of the future value-based healthcare systems. To conclude, [18] described one of the main goals of healthcare services:

> *"The goal is to use health resources optimally, delivering the right care in the right setting and at the right time."*

The following sections will show the other perspectives on sustainability.

3.2.2 Social dimension

The authors in [22] provide a possible definition still here, by quoting [4]:

> *"Social sustainability, in the context of healthcare, relates to the ability of a healthcare system to enhance quality of life and improve well-being of a community. Occupational sustainability in healthcare services involves meeting the demands of changing healthcare operations without compromising the health and wellbeing of the healthcare workers."*

A tacit part of this definition concerns the values of the healthcare system: it is based on the provision of universal and fair access to care. The position of people in healthcare service is focal: the target of their work is the entire community and the actors involved in providing the service are many. It is a complex system based on human resources that has the entire community as a target. Looking from the business perspective is unique. Improving the quality of life of a community means addressing all the issues related to working with a really wide target, that involves inequalities, distances and many differences on many levels. [5] provided a support about this concept:

> *"(. . .) social sustainability turns out to be a nested concept, which concomitantly implies the endorsement of different principles, including equality, diversity, democracy, interconnectedness, environmental friendliness, and individual empowerment. Firstly, to be sustainable from a social perspective, the health care system should allow an equal and non-discriminatory access to care for the whole population, overcoming inequalities produced by individual socio-economic conditions. Equal access requires the ability of health care providers to identify and tackle disparities in the access to health promotion and health prevention service. Moreover, fair and non-discriminatory access to care relies on the health care organizations' capacity to avoid the misuse of available health assets and resources, prioritizing health services targeted to people with higher needs and enhancing the responsiveness of health services providers toward the evolving expectations of the community."*

This is a helpful overview of the meaning dimension in consideration.

Healthcare and the social dimension are strictly related one each other, and below are shown 2 aspects where they are connected. The first one concerns the real workforce of the healthcare system: in operative terms, it comes from employees and their organization, which has a strong impact on working conditions and, for that, also on performance. Talking about efficiency in this sector is not easy, but in this case is clear that hard conditions make the work harder for doctors, nurses and any other operators involved. It happens because the service provided is made up of a social component, related to any interaction and decision that affects the personal dimension of patients.

This is a relevant relationship from which start to discuss the social dimension in healthcare: the work of operators and service providers is based on social connections, that represent a key element for the final goal. It is deeply discussed in the literature and it is a topic of discussion in health providers. So, it is possible to trace a connection from work organization to patient: an indirect link, that represents a part of all the factors, related to any impactful source for operators, patients and hospital organization.

The second aspect for discussing the social and healthcare interconnection is well discussed in a study of [19], where they studied the relationship between social conditions and health by revisioning the literature available. Here, social conditions are defined as the elements pertaining to an individual's relationships with other individuals. These include a wide range of topics, from intimate relationships to jobs held within social and economic societal institutions; where they included also the socially stressful life events, variables related to race, socioeconomic status, and gender and the variables related to the stress process, such as social support. They concluded that social factors play a significant causal influence in the development of illnesses. It becomes particularly pertinent if we consider the previous reasonings and the previous reference: the healthcare system, for providing universal care, should address the issues related to the inequalities and the different socioeconomic and personal conditions, intending the wide range listed before.

Jointly, the hospitals may be, unluckily, a source of stressful life events and, for the same reason, the organization should be able to manage them and avoid the consequences on patients. Then, if we consider one last link between illness and costs where the first affects the second, as shown in the previous section, it is possible to extend further the linkage explained. To sum up all the discussion and reminding that many factors have been ignored for the real goal of this elaborate, there is a line that connects healthcare system organization and the impact in terms of social and economic sustainability, by affecting the working conditions in the middle, then the performances at work and the effectiveness of the cure. It is a brief example of the social dimension in healthcare and considering the multifactorial relation it is far to be a complete description. For instance, here the condition of workers is defined only as 'consequence' and not as part of the question, as it should be.

Instead, proceeding by considering the current condition, the work [29] discussed about lack of this value-based healthcare approach about social inclusion in service delivery. It is supported by Porter and Teiseberg in [27], where they stated that value-based healthcare approaches often place greater emphasis on the person and the economy than on the environmental and/or larger social elements outlined by the Sustainable Development Goals (SDGs).

To fill this gap, there some ideas that have been designed. The authors of [29] supported an idea of care based on social sustainability, by delineating the integration of care, focused on combining the health service with social care, as a real possibility. Also [5] supported this opinion when they discussed how the social sustainability of the entire healthcare system is weakened by the lack of interconnection in the design and operation of healthcare organisations, which hinders the attainment of equality, diversity, and democracy in the provision of health services. Contextually, it is debated the activities for focusing on diversity, by translating it into the capacity to create a system for delivering health services that are efficient in attending to the diverse and evolving health requirements of various patient categories. And it can happen by involving patients in design and planning operations. More precisely, they stated:

> *"In other words, patients and informal caregivers should be engaged by health care providers in a co-producing partnership, which is aimed at minimizing the risks of resources' misuse. The engagement and active participation of patients and informal caregivers is critical to make people aware of the intrinsic complexity that characterizes the provision of health services, thus encouraging them to perform as co-producers of health, through higher compliance, greater willingness to self-manage individual health needs, and better consciousness of healthy life styles and behaviors"*

So, for creating the condition for a sustainable healthcare system, and considering previous claims, the focus should be on social connectivity and inter-organizational relationships.

This is an overview of the social dimension in healthcare, with one possible example of the relationships and some proposals to address the issues of current systems. Followingly, it is explored the last dimension of sustainability.

3.2.3 Environmental dimension

The sustainability concept, in general, is wrongly intended only in terms of the environmental dimension. It happens since the ecological impacts are the most visible and 'direct' cases that reflect the concept of compromising the future. Moreover, this view can be incomplete over all the impacts that our society, or simply the health systems, may have on the environment. Still in this section, the aim is not to provide any list, but a simple example to understand the correlations with the ecosystem.

First, a definition is helpful to outline the borders of the context in consideration. Good support for that is given by the World Health Organization [12] in a document of 2017 where they address the question of the environmental impact of health systems. They started by defining their goal in this way:

> *"A vision for an environmentally sustainable health system is put forth, as being a health system that improves, maintains or restores health, while minimizing negative impacts on the environment and leveraging opportunities to restore and improve it, to the benefit of the health and well-being of current and future generations."*

Their work began with many studies that tried to estimate the impact of healthcare systems on the environment. Someone used the size of the system over the entire economy, as [8] that approximated that 8,6% of global GDP (and 10,8% averagely of national GDP of high-income countries) is covered by healthcare. Some others used the air pollution emissions in all their forms (acid rain, greenhouse gas, smog formation, etc.), as [3] that evaluated the direct and indirect impact of Health Care Organizations (HCOs) in the US as significant over the total emission of the country, describing also the negative effects on the health of the population. Hence in Italy, according to the annual report of 2022 by Agenas ([2]), the national agency for the regional healthcare systems in Italy, the percentage of costs related to energy consumption has reached 3,2 billion (2.3% of total production costs). The scale is not particularly relevant for this elaborate, even if interesting and useful to comprehend the relevance of the question, instead, the goal is to provide an overview of this dimension in the healthcare field, by depicting it through the effects that ordinary and extraordinary operations have on the environment.

The intricated system that provides the service places the cure of the patient in the first place for any decision and aims to reach it at any cost, so the resources to spend for providing the sufficient condition to cure are many. Then, the operational needs have to be joined with the conditions of the structure, where the age and structural issues impact dramatically on the energetic efficiency. From these points, it can be easily inferred that it consumes and produces a lot. For instance, in the US the country's hospitals contribute 2.5 times the carbon dioxide emissions of commercial buildings [10]. Also the general waste production of this sector (still in US) is second only to the food industry. Furthermore, the scrap generation from operations over the entire process involves various typologies of waste. The work [7] stated that HCOs the only companies that generate all the different classes of trash, where 20% of them are considered hazardous due to their infectious, poisonous, or radioactive nature.

In the last years, there has been a trend concerning the attention to the environmental dimension, that drove to the study and adoption of different solutions to reduce the HCOs impact and [22] listed some of them. About circular practises, many procedures arose with medical products to re-use, repair and recycle, or even re-furbish and re-manufacture. Regarding resource management, the following projects have become widespread: transportation by electric vehicles for reducing carbon emissions and conservation methods of natural resources. Then, other approaches as sharing products, waste prevention and treating products as services, have been used to extend the product life and reduce the amount of waste. Similarly, many techniques have arisen to design the physical environment, as integrated facilities design, application of lean principles and systematic involvement of stakeholders in designing procedures.

The main obstacle to the implementation of these measures came from the missing benefits in economic terms, but this is not completely true because here (as before) the factors and sides are interrelated. The first and easiest case to observe is the one related to resource management. The recent years have shown all of us how big are the benefits of having a system that allows us to save energy, the cost increases out of control have created a strong impact all around us. Reaching the condition where the dependency on energy providers is weaker means being more independent from external factors, and it can be really helpful in dramatic conditions. In fact, out of these conditions, the costs related to resources (not only energetic ones) are high to the point that little savings in percentage can give an opportunity for improving the service and impacting, for instance, the social dimension of patients. As said, it is the simplest example but the relationships are clear: from the environmental dimension to the economic and finally social one. In this case, as in many others, the funds are the means for transferring the impacts. But here it is important to remember that aiming to save these funds is not the key, instead recognizing the other dimensions could be the right investment to do.

Therefore, the logic to reinforce is the same: every investment must consider the impact on the other levels. Borgonovi et Al. [5] strenghtened this idea when they debated about the environmental dimension in social sustainability. They claimed that there are at least two serious repercussions when the environmental aspect of social sustainability is neglected. First, the unsustainability of healthcare organisations' environmental practises contributes to the deteriorating state of the environment and has indirect effects on the health of the populace, resulting in higher health demands and a corresponding rise in the demand for treatment. Second, there is a disconnection between the overarching goals of healthcare organisations and their actual conduct, which subsequently undermines their social acceptability among pertinent stakeholders.

Talking about waste management, a good point of view is provided by [23] which discussed the benefits of managing properly waste and supply chain in the health sector. For every detail it is referred to access directly to the document, here it is simply highlighted that environmental efficiency frequently translates into better economic performances, creating value for shareholders and customers. Redesigning the supply chain process (Environmental Product Design) or adopting new methodologies to address environmental challenges (Environmental Management System), allows to handle properly the processes and related wastes, and finally brings economic advantages.

As listed before, there have arisen many approaches to improve the environmental impact of operations in HCOs. There is one more to consider since allows us to involve the connections between factors and address them more completely. It is 'ecological economics', an interdisciplinary field that integrates the logic and principles of ecology within the ones of economy, considering:

> *"the human economy as an open-sub-system of a larger ecosystem (the planet Earth) which is effectively materially closed and finite"*

This is how [15] defined it when they treated its application as a way to consider the environmental impact within the economic evaluation of the healthcare systems. Also here, all the reasonings are referred to in this paper that presents a different approach than traditional ones to address a complex question, as the object of this chapter, that can be useful to consider when a radical change in addressing the environmental impact becomes necessary.

The description of the sustainability concept in the healthcare sector has been wide to involve the necessary to be comprehended as best. The following section focuses on the concrete solution that can support the measurement of these dimensions.

3.3 Assessing Sustainability in Healthcare

The previous chapter tried to give an overview on the size of the impacting levels on sustainability, showing the presence and importance of relationships, and briefly presenting some approaches that can be adopted to improve them. Considering the goals set by UN [25], the interrelations among them fig. 3.1, the direct and indirect impact that a factor may have on others: it is evident the necessity of current healthcare systems to be re-designed by including new structural changes.

Thus, before envisioning any project for improvement, it is necessary to have a measurement system: for defining the direction to take, for understanding the current condition as well and for setting the objectives to reach. Any data-driven approach needs to include one step: define the "as-is" condition. This aims to set a common and objective starting point for everyone and every reasoning, as precise as possible but for the precise goals set in advance. Additionally, in this case, this operation will provide a new perspective on the system since it has never been observed in these terms. So, before developing any reasoning, it is required to understand the logic of the new lenses and this is the goal of this chapter. More precisely, it describes some introductory strategies that can be followed for this approach and that can be integrated with the object of the thesis.

The previous pages enlightened one concept: a multifactorial system has a notable degree of complexity in addressing it. Here, the possible sources of sustainability are many, as the direct and indirect linkages among them. This wide size of elements, points of view, and impacts to include in the analysis places the responsible entity for improving sustainability in a difficult condition where something is clear but there are surely a lot of unknown elements. The problem is the darkness of these dimensions, so the proposal aims to light up on the topic trying to trace some lines to follow for any reasoning about, by an initial and theoretical work that will become concrete in the following stages. Given that, a possible approach for this situation is provided by [22] and below it is described in the biggest elements. It is not the only or the definitive one, but it has been considered a good proposal from where to start for further development. The basic idea is the definition of macro-sustainability measures able to support an integrated system methodology for bringing improvements to HCOs.

Measures for sustainability proposed by [22]		
Environmental	Circular Practices	It is the concept of keeping resources in use for as long as possible through their recovery and re-use following cradle to cradle approach.
	Facilities Design	It refers to the architectural design of a hospital facility including its technology and equipment and its effect on patient safety. Need to create a truly healing environment that comprises of nature, daylight and fresh air.
	Waste Reduction and Management	The goal of waste minimisation is to reduce to the greatest extent possible, the waste that is destined for ultimate disposal by means of re-use, recycling and other programs. Approx. 80% of all HCW can be disposed of through regular municipal waste methods. The other 20% can create health threats if not disposed of properly. Disposal methods vary according to type of waste, local environment, available technology, costs and financing and social acceptance.
	Sustainable Procurement	It is about combining social and environmental factors with financial considerations when making purchasing decisions. It involves making decisions based on life-cycle costs and associated environmental and social risks and benefits. These include mercury and PVC plastic phase-out as well as substitution of toxic chemicals.

Continuation of Table 3.1		
Social	Patient Satisfaction	It is the extent to which patients are happy with their healthcare. A measure of care quality, it gives providers insights into various aspects of medicine, including the effectiveness of their care and their level of empathy. Its level is directly linked to key success metrics for hospitals.
	Employee Satisfaction	Job satisfaction has been identified as an important factor in healthcare staff retention. It has been found to affect quality of care, patient satisfaction and turnover.
	Affordability	Fundamentally, affordability is a function of income, spending and judgments about the value of goods and services for their price. A healthcare facility should be available (24×7), accessible and affordable to all.
	Sustainable Health	Focuses on prevention of diseases and promotion of healthy lifestyles through vaccines, exercise, yoga, meditation, healthy food etc.
Economic	Green Growth	The incorporation of environment friendly practices into healthcare delivery such as a green hospital. In its simplest expression, a green economy is low carbon, resource efficient and socially inclusive.
	Research and Innovations	Research and innovations are the critical factors to realize radical change because they possess the potential to contribute to fundamental changes towards sustainability. In the context of healthcare, improvement programmes such as in clinical practice, nursing practice, reducing the cost of healthcare etc. falls in this category.

Continuation of Table 3.1		
	Savings in operational costs and enhanced profits	Reducing the total cost of care delivery is of vital concern to healthcare providers worldwide as this is the only way to improve the bottom line. This economic aspect covers strategies that promote cost savings, profits and research and development. Savings in operational costs may be achieved through green growth of the sector, indigenous production of medical instruments and devices, non-invasive approaches, telemedicine etc.
	Indigenous Production	India's medical technology industry is primarily import dependent; only 30% of the country's requirement of medical devices is being met through indigenous production; that too of low end category. However, India is called the pharmacy of the world and it is fast becoming the hub for innovation and manufacturing.

Table 3.1: The measures of sustainability in healthcare provided by [22].

The table 3.1 lists and describes them with all the contributions, which can help understand the related benefits. Just a brief explanation should be done on the last point since the document studied the Indian system and this aspect has been considered relevant for their capacity to produce medical devices, that logically may change from country to country.

However, the presented frame is not detailed at the point to assess the effects of the healthcare system and it does not aim to work for that. Its goal is to provide a wide lens for looking at the internal processes and search autonomously the specific measures, distinctive for each case, able to outline the rough borders of the "as-is" situation. A point to remember in this process is that people involved must be aware of the meaning of sustainability and, mostly, of the processes to discuss. The description of reality is done by those who work at a distance from the processes, but from employees in direct contact with the object of the discussion (e.g. doctors, nurses, warehouse operators, pharmacists, etc.). For example, a good usage of the tool may work by examining each measure of the table with people close to that and determining the real factors affecting it inside the specific context, by setting some KPIs able to survey them.

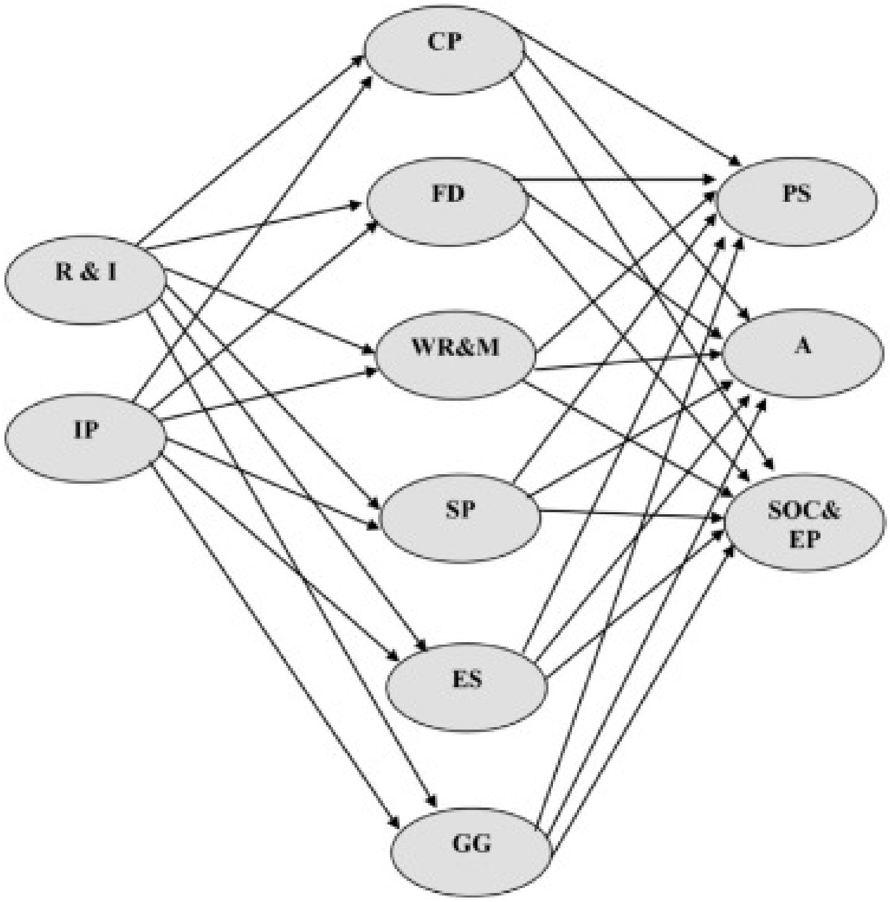

Figure 3.2: Description of the interrelations among measures for sustainability proposed by [22].

Thus, considering what was discussed before, a strict analysis of direct causes is not enough and it is necessary for a wider view to include the relationships between factors. The paper ([22]) provided support to define them in the fig. 3.2, with the measures depicted are CP (Circular practices), FD (Facilities design), WR & M (Waste reduction and management), SP (Sustainable procurement), PS (Patient satisfaction), ES (Employee satisfaction), A (Affordability), GG (Green growth), R & I (Research and innovations), SOC & EP (Savings in operational costs and enhanced profits) and IP (Indigenous production).

This is the result of involving many experts and applying certain techniques, where reference is made to the paper [22] for every detail. It is a multi-layer framework that depicts the connections between the measures found, by creating a flow among the driving (and independent) measures, with linkage (and mediating) measures and dependent measures. This support may work with the proper measures that emerged using the table table 3.1, which can be explored in deep with this diagram to define their relations. Exactly as the specific measure definition, the operations can work with the people effectively involved in the process object of discussion and these connections can be taken as examples to determine the ones present in each specific context. Using it, however, requires being aware that they can be partial to define the direct connections, and it is completely missing of indirect ones.

Summing up, to enlighten the darkness of sustainability connections there have been presented 2 supporting tools that can be used with the descriptions and papers of the section 3.2 for discovering all the relevant elements. As before, this process is intended to be supported by people directly in contact with the topic of discussion. But it must be reminded that the work for assessing sustainability in healthcare is far from being completed since it is just a theoretical plan and all the concrete process is still to be developed. For this reason, the following section has presented digitalization as a real opportunity to build solutions to support the journey toward sustainability.

3.3.1 Digitalization as part of the solution

This chapter places an evolution and continuation of the previous reasonings: it is going to describe a means that can actualize the benefits coming from factors exploration.

Previously, the attention has been on the “as-is” condition, intended as the current situation of a given system. All the reasonings allowed us to trace some borders and, possibly, outline the factors to consider in the analysis, but the complete picture of the system is not finished. The following steps can be many and they should pass from the analysis of the processes, for depicting the real activities to measure for collecting the information required. Then it is necessary to define and set up the data collection procedures, that require to be managed and integrated on a reference point for all the information regarding a macro-area. However collecting data without analysing them is apparently useless, so the reference point should be linked or directly involve a support to access and investigate data, with the final goal to improve a certain situation. Finally, the new condition needs to be measured to understand if the plan and the investment follow the expected behaviour. The point is: that processes and related complexity are still many. As before, it is required to have other supports to address them, and here it is discussed why digitalisation processes can be a good opportunity for that.

The authors of [35] treated the question, by starting to outline the issue and its origin. The UN SGDs came out with the goal to be the reference for the development of future projects or investments in any field, expecting that entities and actors involved would organize their work together and cooperate for them.

It is possible to shape the question in the global context, where all the countries are together to address this question; but it can be observed also on smaller size dimensions, such as the one of a country, region or business sector. In this question, the digital revolution and technologies are portrayed by the authors as means to bring new possibilities and pathways, that have an enormous potential to contribute to reaching the sustainability of the human and planetary systems, or at the very least, to lessen the adverse effects of human activity.

The term 'potential' is willingly used since it is broad, but here it is needed to form into the context. The power of technologies in this case comes from their capabilities to share and collect huge quantities of data, then to process them rapidly and provide meaningful information. Over the years this has been used to solve some known problems, such as matching people with advertisements (social networks), connecting assets with different actors to allow the sharing of resources (Cloud platforms and sharing services) or, widely speaking, matching needs of two actors to satisfy it reciprocally. Over all these cases the digital support has been able to create an environment to interconnect many actors and flow the information among them.

The point to learn from these situations is that the value has been generated from the information exchange. This is the power we are interested in of new technologies and digitalization: creating value by sharing information. This idea is commonly shared, as [21] that reinforced these ideas by setting the focus on the creation and acquisition of value from the ecosystem, intended as the group of actors and stakeholders of a business sector that interact together. In that elaborate, they presented the networks as places where:

> *"(...) all actors are resource integrators in a network of other actors, and thus all actors are potential innovators or cocreators of value."*

Within these 'networks' the information flows are rich due to the complexity of the connections and the cooperation of the actors, so the increase of connections and their power and speed becomes a boost for the development of the ecosystem.

The explanation of the concept of ecosystem is really short (and partial) and requires be extended for exploring the topic more completely, so it is referred to [36] for deepening the topic and in particular the Digital Business Ecosystem. Most of the studies in this direction concern the economic field (since it has been the one considered most important up to now, as well as the most profitable) but the concept may work also on the sustainability dimension. On one side there are goods, boxes and warehouses and, on the other, resources, tubes and environmental sources. However, defining the right dimensions for the context considered (e.g. following the suggestions of the previous sections) would allow us to transfer the same reasoning from the strict economic dimension to all the levels of sustainability.

About the topic of the thesis, many other analysis and research has been conducted at different levels of the discussion. The authors of [32] explored the elaborates done about ICT in support of sustainability, by organizing them into the 3 basic sustainability strategies: efficiency, consistency and sufficiency. It can be extremely useful for further development to focus the academic work on the necessity of the community. Other important improvements come from various health systems across the globe that investigate how healthcare delivery could be made more sustainable way by minimising its adverse effects on the environment. [26] approached the question by focusing on the relationships: understanding them and building solutions that consider all the dimensions. He depicted 3 challenges that our society has to face to build a more sustainable service, where the main goal is devising interrelated solutions able to improve the health of the present (or near future) without harming one another elsewhere or in the longer future.

Here it has been shown which are the issues we have to face in the path to sustainability, by providing a possible perspective for the situation and demonstrating why digitalization can be a good opportunity to address the question.

Chapter conclusion This section concludes the discussion about sustainability and it is necessary to remember the role of these pages, which are a starting point for further and detailed development of specific cases. The following chapter is going to explore the technology (and approach) core of this thesis and its potentialities for the usage described above, matching its strong points with the necessities of the sustainability analysis.

Chapter 4

Digital twin: value and opportunities

The focus of this chapter is on the Digital twin (DT). The discussion will focus on the technological approach, the paradigm and the role that it may have in reinforcing IRST operations.

The presentation starts with a general description of the concept and its origins, followed by an exploration of its functionalities and potentialities. Then the discussion is deepened into the real value proposition provided by DT, understanding the opportunities that it provides. In conclusion, some developments in the Healthcare sector are presented, with particular attention to some recent papers that provide a valuable approach for the IRST case.

4.1 What is a Digital Twin?

Many studies discuss about Digital twin applications, by providing some definitions from their perspectives. There is no definitive definition or deployment process, instead, it is general and ambiguous for those who approach it for the first time. This is the outcome of the work done by Liu et. Al [20] after a deep literature review, that is a good source to various developments for any further investigation.

However, there are the basic ideas that most researchers and managers agree brought to an evolution: from the context where it birthed to various sectors where the application has been considered meaningful. Here, the focus of the discussion is not on the precise definition, even if some are used in the following pages, but the attention is moved to the value transferred and logic at the base of this approach, understating why it is an opportunity for improving sustainability in IRST.

The first appearance of the concepts comes from the 2002 when the Dr. Grieves proposed a solution for a Product Lifecycle Management (PLM) [14] based on the

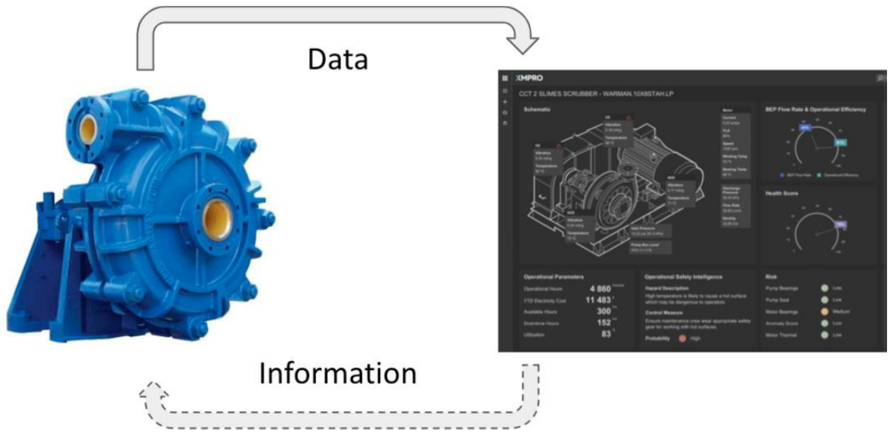

Figure 4.1: First conception of Digital Twin (from [24]).

presence of 2 elements that exchange data and information: one is the real object of interest and the other is its virtual representation. It was the basic idea of Grieves: a copy that receives data from the real world to mirror the behaviour of the real object but on a different dimension, where all these data can be elaborated and give back information that the real object does not have. The picture fig. 4.2 shows an example of a pump with its virtual copy.

Grieves jointly discussed the 3 basic concepts behind this first version of DTs, intended as some fundamental ingredients to build it. Varan Nath and van Schalkwyk in the book “Building industrial Digital Twins” [24] described them as below (with related picture):

- The Digital Twin Prototype (DTP): the representation model of the physical object. It is a single description of all equal objects (eg. all the pumps have the same prototype) that is used to build all the ‘variants.
- The Digital Twin Instance (DTI): the precise instance related to a precise physical object. It is the specific representation of an object, called before as ‘variant of a DTP’.
- The Digital Twin Aggregate (DTA): the set of DTIs and DTAs integrated with the mechanism to access them. It is the group of instances and eventually other aggregates that allow to describe a system of multiple objects.

The description of these appeared important for two reasons: first, the distinction they provided between ‘model’ (DTP) and ‘data about specific object’ (DTI), which often is the source of misunderstandings in any discussion. Second, Grieves introduced the idea of combining multiple digital versions to represent systems, from simple ones to more complex where multiple DTs are nested and integrated

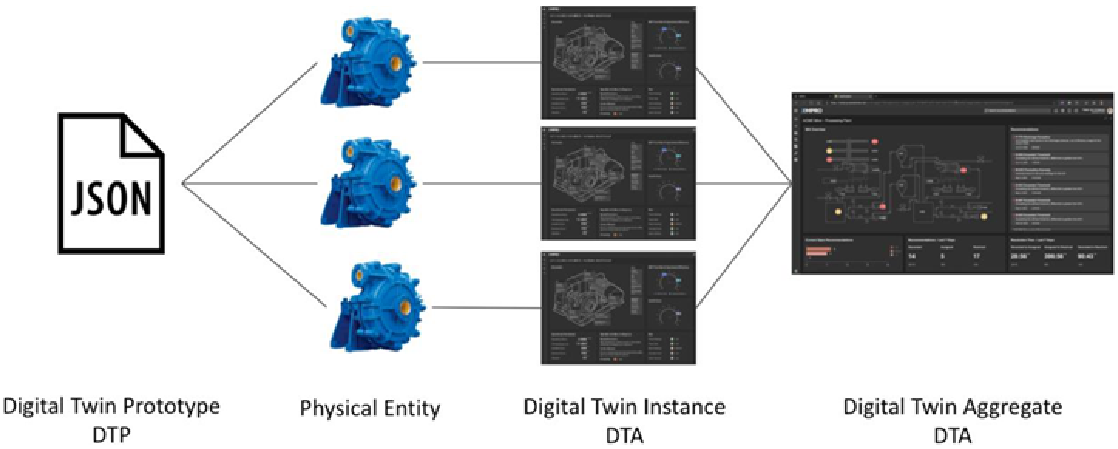

Figure 4.2: Three basic components of the Grieves proposal represented by the example of the pump (from [24]).

to describe the internal mechanisms. This modular approach is one of the key reasons that makes the DT so powerful.

To stress the importance of the second point is needed to repeat a concept differently: DT can represent complex environments by aggregating multiple elements, and these allow us to represent relationships and the impacts on the assets into consideration. An example helps to easily explain the idea: supposing to have an environment with multiple engines where each of them produces heat caused by the dissipation of the energy used to work. The engines work properly under a certain temperature, otherwise, the inner mechanisms could be damaged and the entire system may break. So, assuming we are interested in monitoring the temperature of devices with sensors to avoid unexpected break (and heavy costs), we may proceed to insert a device (with a thermometer) inside each of them and set a threshold where the machine has to slow down. At this point, what happens if the machines are not able to detect an external increase of heat? For instance, there may occur a situation where a group of machines (or external factors as well) heats the environment outside up to the threshold and the other machines continue to work at maximum instead of slowing down because the inner thermometers (considering that the propagation time is not zero) are not able to detect (in a short time) the external heating. The consequence is obvious: these machines may break even if the controllers were installed and properly working, and it happened because the monitoring system did not consider the impact that an engine has on the others.

This is a completely different example from the topic of the thesis, but it is a physical situation where the consideration of the information about the relationships between machines is critical to avoid breaks, which means costs and service interruption. Having DTA allow us to consider the connections and extract additional insights that may be valuable as well as the data coming from the object, or even more.

As anticipated the definitions of Digital Twin are many without any definitive one where all experts agree; so here are reported the ones that focus on relevant concepts for the work done. Below is shown the one provided by Varan Nath and van Schalkwyk [24]:

> *"A Digital Twin is a synchronized instance of a digital template or model representing an entity in its lifecycle and is sufficient to meet the requirements of a set of use cases."*

There are two keywords here: the first one is 'requirements' because the presence of a DT is based on precise needs that are planned to be satisfied by this one. The process for development must start from the detection of specific necessities and it must involve an analysis to understand whether the DT is a solution or not. Moreover, this word is related to 'sufficient' which encloses the idea that a DT should represent an object in its essential features, where the essential nature is given by the necessities collected.

The second is 'lifecycle' because it highlights the idea where the objects represented are different: some are 'everlasting' (eg. buildings), others have limited life (eg. products) and it is based on the previous point, so the expected uses with that object.
So, the DT represents an object in its indispensable features for reflecting the specific needs collected, which brings to have a certain lifecycle dependent by them.

Then, to provide an overview of the DT concept it can be useful to look at the definition done by the Digital Twin Consortium [39], where they described it by answering to 'W questions'. Below are shown the answer to what and how:

> *"A digital twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity. (...) Digital twins are motivated by outcomes, tailored to use cases, powered by integration, built on data, guided by domain knowledge, and implemented in IT/OT systems."*

There are some extremely important concepts here. One is the possibility to represent processes and not only objects, which extends widely the opportunities of this approach. Then, it introduces the concept of 'specified frequency and fidelity', that is the frequency of updates between physical and digital objects and it describes the ability of DT to represent the objects in real-time.

The notions provided in the book [24] are strengthened, by introducing another key criterion in the development operations: the domain-driven approach. This

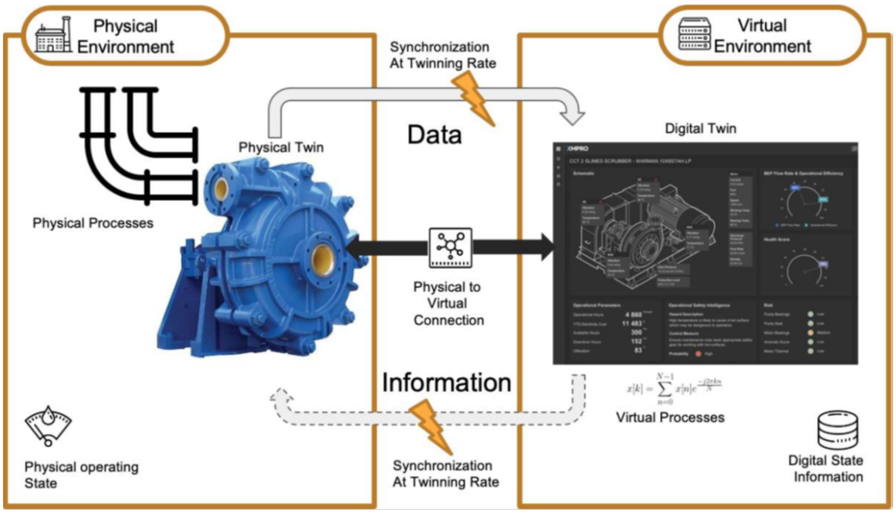

Figure 4.3: Detailed description of the Pump and its Digital Twin (from [24]).

methodology is based on the inclusion of domain experts into design operations to guarantee an effective development process, based on the real descriptions without having any issues of intermediation. In this case, the benefits are on the definition of essential features based on reality and real needs.

Part of this approach is based on clarification of terms, so in the schema fig. 4.3 and related description table 4.1 are shown a brief explanation of the characterizing elements of Digital Twins [24].

The picture fig. 4.3 describes clearly the mirroring ability of DT. The physical processes and state are represented by data, formulas and calculations, without being strictly related to a technology. Fundamentally the implementation is not related to the logic of the approach, it depends on the cases, necessities, resources, contexts and so on. The definition of the virtual elements is disconnected by the physical realization or better, the implementation depends on the needs that the system has to satisfy but it is not defined a priori how it should be realized, that instead may depend on many other factors (resources, available time, know-how, etc.). Since the DT is not bound to technology, someone talked about "Digital twin paradigm" [13], concerning the approach out of the concrete implementation.

Then, a crucial role is the one that makes them a 'twin', that is the synchronization and the connections that move the relevant physical information into digital data. The speed of these updates is called the 'Twinning rate'.

A concept needs to be reinforced here, especially talking about physical and virtual environments: this representation does not reflect the entire system in all its complexities, because it would be impossible and extremely complex. These virtual elements are a copy of reality in a way that makes them useful for extracting

Characteristic	**Description**
Physical Entity (Physical Twin)	”An entity is an item that has recognizably distinct existence, e.g., a person, an organization, a device, a subsystem or a group of such items” ISO/IEC 24760-1:2011
Physical Environment	The real-world environment that the Physical Twin exist in (factory, oil platform, hospital, nature reserve, etc.)
Virtual Entity (Virtual Twin)	The virtual Digital Twin prototype (DTP) and instance(s) synchronized with the physical entity at a twinning rate
Virtual Environment	The technology-based environment that the virtual Twin exists in
Synchronization (twinning)	Synchronization or updating the state of the physical twin and virtual twin
Twinning Rate	The rate or frequency at which synchronization happens
State	The values of all the parameters of both the physical and virtual Twins in its environments
Physical to Virtual Connection (bi-directional)	The communications and data connections or processes used to establish this synchronization of the state at the prescribed twinning rate
Physical Processes	The processes in the real-world environment that will change or impact the state of the physical twin
Virtual Processes	The processes in the virtual environment (such as analytics or physics-based calculations) That will change or impact the state of the virtual twin

Table 4.1: Description of elemenrs of a DT (from [24]).

the relevant data. Their definition and deployment, strongly supported by domain experts, is based on an 'outcome-driven approach', where the needs define the depth of descriptions. The resources available to spend in the design phase are a consequence of the description, but there are no bounds and it is another question.

4.2 Functionalities

Above it has been described what is a DT, how is it composed and some key concepts. But there are not mentioned the potentialities that are brought to the development, intended as operations and opportunities that bring concrete benefits.

To introduce and discuss them, another part of the definition provided by Digital Twin Consortium [39] is valuable for that:

> *"Digital twins use real-time and historical data to represent the past and present and simulate predicted futures."*

Assuming to divide this sentence into 2 parts (where the first ends with 'historical data'): the first one argues the sources used by this system to work and the second one is about what a DT can do.
Talking about the sources, DT works by the real-time data that enable to twin by representing the physical entity in its essential features, as shown in the pictures fig. 4.2 and fig. 4.3. Then, when these data are updated by new ones, they become 'historical' and they still represent a precious source of knowledge, but from a different perspective. Their value is no longer dependent on the accuracy of reality or fidelity for a certain synchronization, but it is related to the attributes: the time, its relations and any other parameters (detected in the design phase as important).

At this point, it is easy to infer the necessity of support to manage these data, something like an aggregator across the lifespan of the DTI. It is known as 'Digital thread' and it is defined as the element that:

> *"(. . .) creates a traceable, unique birth record with the actual data for each composite entity or product assembly and all its components"*

The authors of [24] focus on this object for its extremely valuable operation of tracking the evolution of the model, which is used to extract some critical information for the 'Physical environment'.

Then, the second part of the definition argued about what DT does with the collected and structured data:

- Representing the present is the most known functionality that DT enable to do, and the opportunities it brings are many and depend on the specific context. In general, it concerns the monitoring operations in each situation where real-time data is extremely precious for decision-making procedures. For instance, in the automotive sector, a DT can support real-time telemetry to offer maintenance services or support at a distance, based on the condition detected by sensors of the car.

- Then, looking and analysing the past is another well-known opportunity to extract value. The support is provided for descriptive and diagnostic analytics procedures [6], focused on understanding 'what happened' and 'why respectively'. It is possible for the sufficient details provided by DT due to the abstraction level defined in the design phase. A possible case may regard the industrial sector when the managers are interested in understanding the reasons behind an interruption in production.

- Finally, an extreme potentiality of DT is given to the possibility of using the data collected for predicting future conditions. This is the case of predictive analytics [6], the study of what is likely to happen, that may be the source of rich information that can strongly impact the present. An example can be the prediction of energy demand per consumer (from utilities suppliers) based on the use of Machine learning algorithms, to create a competitive advantage.

The 'representation' cited above involves much more than simple storage. But in this term are involved also the information, intended as the knowledge with high value in the real world (the return arrow of fig. 4.2). As anticipated, the definition of this information is made in the design phase.

The authors of [24] argued the presence of 2 possible scenarios for obtaining them:

- Simulation: it refers to the operations in which the virtual environment is used to test 'what-if' conditions: situations where the current condition does not allow to know certain information and it is necessary to reproduce hypothetical conditions to gather them. In the case of DT, the people in charge use the model to verify how the data and outcomes would change in front of a variation of a parameter.
  For instance, it is recurrent in an industrial context where is needed to modify an existing product. The devise phase includes also the test phases and having a DT means enabling virtual tests. They do not replace at all the physical ones, but they reduce them and the related costs and waste.

- Operational: it is intended to describe all the operations executed by the support of DT on the data collected. The applications may concern access to 'real-time' data or even the ones about the past for observing the evolution, which often involve the use of specific tools. Different to the previous case, here the data considered are real and not hypothetical. Both sides are valuable but in different ways.
  The examples in this case are many and include all the cases where the collected data are used to extract information.

This differentiation done by the authors is not to be considered as definitive or milestones, also here the literature is general and not in agreement on a single idea.

Additionally, another distinction of [24] is relevant to be discussed to explore better the meaning of DT. The design phase has been defined as critical for its ability to represent data to gather information, and it happens by the definition of the model. These can be in the form:

- Physical based: engineering calculations that reproduce the reality under a certain aspect that, given the data, describe physical entity state. One clear example can be the testing procedures of a product under the extreme conditions described by the physics laws.

- Analytical based: model mathematical and statistical based able to predict the states of the physical twin and its environment. Here the most known example is provided by AI and Machine learning algorithms.

- Visual: the visual representation of the object appears to be extremely important in each case where the visual analysis of different data is the key for extracting information. Eg. Virtual Reality (VR), Augmented reality (AR), Computer Aided Design (CAD).

The best one to use in each case is obviously due to the use that needs to be done, as well as the resources to invest. These are many aspects useful to provide the basic knowledge about DT functionalities for addressing and explaining the work done during the internship. Below it is discussed the value really delivered by this approach.

4.3 Value proposition

The previous sections have described the meaning of DT, the operations to carry out, from which is possible to derive the possibilities that make it concretely convenient to adopt a system like that and the opportunities in many different sectors.

Thus, they are not enough to describe the value delivered by this support to the adopters.

Digital Twin Consortium [39] proposed with the last definition piece, precisely the one regarding the "why" question:

> *"Digital twin systems transform business by accelerating holistic understanding, optimal decision-making, and effective action."*

This sentence is structured as a flow: from the holistic understanding follows the decision-making processes, and then the actions adopted. The Digital Twins support these steps by making them easier than traditional conditions, as a catalyst in business operations. The transformation occurs since the traditional operations are supported by this technology, which radically changes the effort needed to take an action.

Over this process, digital support makes the access and consultation of information faster. If it is joined with a model that outlines and tracks the precise information useful for comprehending the physical environment, an easier holistic approach is guaranteed. This was the goal of Grieves when he proposed its solution, and it is well described by himself and Vickers in [14]. They started from by describing complex systems in terms of their non-linear interactions where the sequence is unexpected, indicating as responsible for the low capability of a system component to detect stimuli. Considering humans as part of the sociotechnical systems that compose our complex businesses, the authors concluded by depicting the Digital Twins as an opportunity to gather inputs and comprehend the non-linear interactions. More precisely, the DT aims to replace the investment of resources required to manage complex systems (eg. time, energy and material) by providing the specific information required. And it is the reasoning to do for motivating an investment in this sense, by comparing the hypothetical expenses of managing these complex situations and the ones required for setting up a DT.

The Grieves' idea has been maintained over the years, and it is possible to find additional confirms as the one by Ricci et. Al [30]:

> *"(...) the DT principles and paradigm can be extended to the virtualisation of complex realities composed of interrelated assets, possibly belonging to different domains and different organisations, in a more 'open-system' perspective."*

This is the core of engaging a DT in decision-making procedures: the consolidated data integration strategy offers more accurate and trustworthy insights, which raise the quality of decisions and actions taken. This is done through all the functionalities described previously.

Varan Nath and van Schalkwyk in [24] illustrated the value provided by this improvement from two operational perspectives:

- Improving situational awareness. To understand why it represents a benefit it is necessary to start from the logic that the condition of a business or healthcare organization is sensitive to many internal and external factors. Their impact as a single may be short but by joining them with their correlations the dimensions can increase rapidly. They may be concerned the internal activities, equipment breakdowns, and external events (from medical to political ones). Over all these situations real-time information is critical to respond precisely to the needs of the moment.

  The power of this support can be improved by including advanced intelligent agents, that may be even able to act autonomously and evolve from predictive to prescriptive analytics [6].

- Improving business outcomes. The potentialities of observing the past, simulating and predicting the future aim to have an impact in economic terms. It may happen by increasing revenues for productivity improvements or business model innovation, or cost reduction for optimizations in supply chain and maintenance; as well as improvement in customer experience or reduction of risk.

  Most of the impacts considered in [24] are transferrable also on the object of the thesis but, since it does not concern a business, the proposed improvements are not satisfying. Here it is considered only the economic dimension, and joining the work presented before about sustainability factors (section 3.3), the outcomes would extend to the other levels.

The same reasoning can be done when the discussion is moved to the value at stake. Still from [24], the authors proposed the use of a framework to assess the value and the impact of introducing a system as the one of DT. It is focused on providing an overview of the situation to stakeholders when is necessary to decide between Digital Twin. It is shown in the schema fig. 4.4 where it is easy to notice the distinctions done. The first is about the levels of value exchange in the industry: one is the value migration and concerns the value shifting between stakeholders, and the other is the value addition and is about ordinary operational opportunities such as revenue increase or cost reduction. The second branch from the origin (the one below) represents the improvement of society and it recalls the concepts discussed in the sustainability chapter (section 3.3).

The (fig. 4.4) is considered a good proposal for future discussions with stakeholders, to use when the analysis for the realization of DT has been sufficiently deep to provide reasonable values.

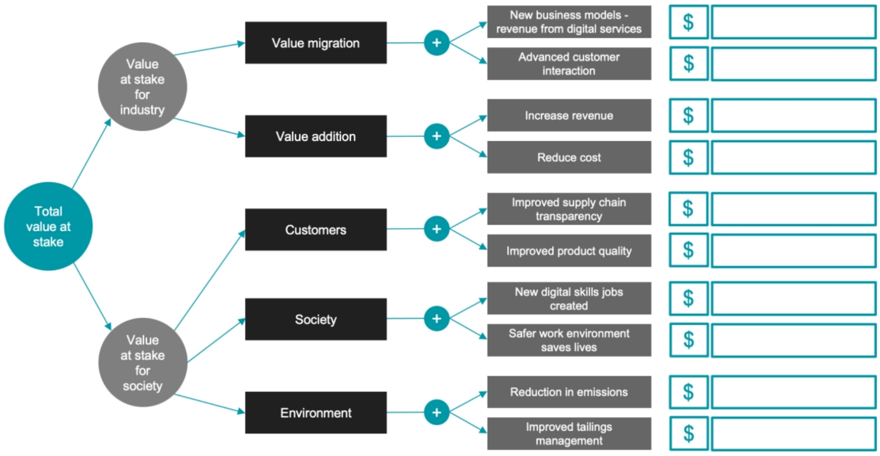

Figure 4.4: Template for the evaluation of the 'Value at stake' in the design phase of DT (from [24]).

4.4 Digital Twin in Healthcare

Healthcare is one of the many sectors where Digital Twins have become popular. It happened for many reasons, such as the wide opportunities provided by the enormous quantity of data managed by the organizations in this sector and for the wide potentialities and benefits that our society may get.

The works in this direction have increased for the appeal generated by some proposals. The first of them is surely related to the virtual representation of patients and their organs ([34]), which would require additional work (as systems for data collection and sufficient models that represent the human body) but they would have high potential for simulation tools and monitoring opportunities. Having a holistic view of a patient would allow to provide a more accurate and more effective medical treatment. As well as the digital view would also allow access to patient's data by distance, enabling in this way telemedicine and all the benefits largely discussed in recent years. Instead, moving the attention from the patient to the hospitals and using DTs to represent part of them would increase the effectiveness of operational choices; for instance in the management of logistics and supply chains in cases where the production is internal.

Based on these opportunities, there is one fundamental reason that makes the DT a real improvement: it is the complexity of the systems. The national healthcare network is a system composed of many nodes (hospitals, aid centres, general practitioners, etc.) that have to be able to reach every person on the national ground, by sharing the resources and cooperating with different actors. Cooperation is necessary because the service provided is composed of the processes

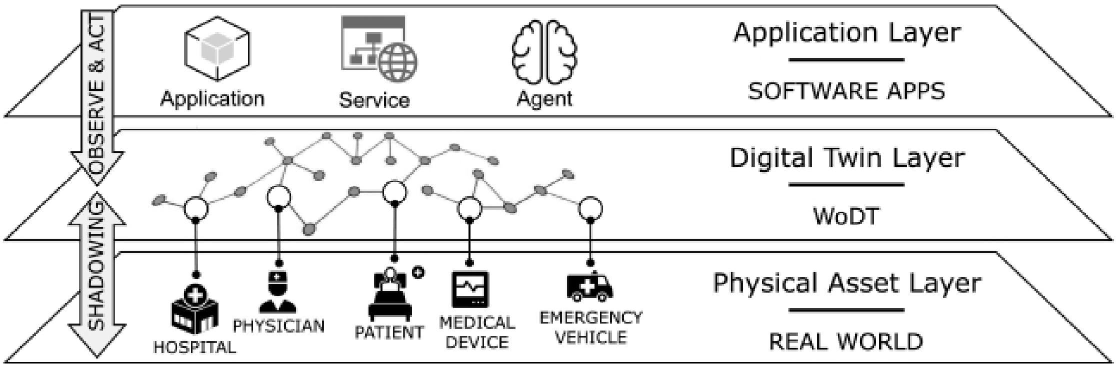

Figure 4.5: The WoDT Layered View (from [30]).

of multiple actors. This may represent an obstacle for certain reasons but it is also a big opportunity for providing a more efficient service by reducing costs. From this idea, there have been some proposals for a new approach to manage the complexities.

Ricci, Croatti and Montagna in [31] presented a support for Trauma management system based on a DT tracking the strategic assets, proposing in this way a new vision for handling this situation based on the accessibility of virtual elements. This is another potentiality that DT can provide by including technological solutions and standards at different levels, that allow to creation of a common language where all the assets (at least in the same sector) can interact one each other for different purposes. Here the presentation has been generally talking about 'information extraction', but it can happen in many ways depending on the way data are used and who can access them.

The same authors with Mariani in [30] extended the concepts presented in the previous reference: they proposed the approach of Digital Twin for the management of an entire ecosystem (called 'Web of Digital Twins'). They focused on the possibility of leveraging standards and modular components to build up an *"ecosystem of connected digital twins"* ([31]). Proceeding in this direction means extending even more the concept proposed by Grieves of Digital Twin Aggregate [14], moving from a restricted context (trauma management) to the wider dimension where it belongs (hospital), by gathering all the insights coming by the holistic perspective up to this level and increasing the benefits in the same way.

They proposed a schema (fig. 4.5) where the DTs layer is placed in the middle between physical objects and applications: from the bottom, the DTs receive the data needed to represent the virtual entities in their essential features, and then they are provided in a structured way to the applications, generally described as 'intelligent agents', that can elaborate and execute operations from them. This model is based on the idea of extending the abilities of physical entities by digital ones, which is supported also by Saracco in [34].

The huge potentialities are due to the interoperability of the DT: it means that the data collected can be provided to any intelligent agent that can extract valuable information. It can be an internal or an external actor for executing any operations, as the ones described in the chapter section 4.2. For instance, when 2 healthcare entities cooperate (as IRST and AUSL section 2.4) they are part of the same 'supply chain', which means that the activities and conditions of one are impactful on the other. It may concern product provision, sharing of laboratories for blood analysis, production of therapies and several other cases. The limit of a similar system is given to the privacy / legal issues and by the ability of humans to understand the information hidden behind data.

The interoperability opportunities are strongly supported by systems that allow to management data in a structured way. In the paper [30] is shown how the Ontologies and Knowledge Graph are fundamental for that, as well as the standards that support them (eg. FHIR). Then are provided further details, such as an abstract model and a general and adaptable architecture that can support the capture of key aspects of different applications. For any detailed study, it is suggested to refer to it.

Chapter conclusion The point of this section has been to show why the healthcare sector is a good environment for the evolution of Digital Twin systems, as well has been presented some ideas at the base of internship's work. The reasonings can be easily extended by including the sections about sustainability: the focus broadens but the complexity and related potentialities remain. This idea has been the base for all the internship activities, which are described in the following chapters.

Chapter 5

Improving the Processes in Sustainable Terms: an Analysis

The contribution given to IRST during the training period begins with this chapter. In particular, it is an analysis of the challenges and criticalities in the process of producing cancer therapy, through an approach based on the values provided by the Digital Twins. As an analysis, this section will in no way discuss the implementation of support but will adopt a method based on the benefits of DTs. In detail, this will be developed by observing a complex dynamic where multiple factors are at work with the aim of extracting valuable information that allows one to deal with this circumstance. Therefore, the aim is to provide a broad description of the situation, in order to contextualise each step within IRST's operations and outline the relationships and needs between them, along with a more detailed study of those critical issues that emerged in meetings with domain experts.

As anticipated, the drivers of this experience were IRST's need to address a new challenge (CCCRN) and the opportunity provided to re-design the processes and tools to support management. This was combined with the desire to move towards increasing sustainability and to monitor the impacts of its operations. The work has been carried out based on these points and will be presented through the following structure: first the methodologies adopted will be discussed (section 5.1), then the differences between the current and future conditions will be introduced focusing on the challenges for Pharmacy and Warehouse (section 5.2). From there, the analysis will be brought to the core with the explanation of the therapy production process (section 5.3) and the critical processes that have emerged (section 5.4), where the dimensions relevant to the circumstances under consideration will be taken into account.

5.1 Methodologies

This chapter delineates the methodologies adopted for the analysis of the context, intended as the operations taken to understand and interpret the organizational landscape. Each method has been employed in agreement with the Healthcare Direction Unit to ensure the extraction of meaningful insights crucial for the subsequent analytical chapters.

In the previous sections has been discussed many times the relevance of collecting knowledge properly, in the internships the methods adopted have been the following:

- Personalized exposition of the therapy production process into the Pharmacy and Warehouse.

  Deep explanation of the activities done, seeing directly the operations, the environments, the products and the production locations. The real value here has been understanding concretely how the processes are done, talking directly with workers and discussing some issues that they face daily. This moment helped me to get quickly into the environment and participate in other meetings.

- Internal meeting for the evolution of processes due to the CCCRN project.

  My arrival in IRST has matched with the execution of meetings for redesigning the internal activities. The new condition of IRST (with CCCRN) allowed for improving the way the operations are done, and being present in these situations has been another moment to comprehend how the activities work and where they can be improved.

- Ordinary meeting with Healthcare Direction Unit. Since the first stages, the reference for my work has been my tutor (who is the co-supervisor of this thesis) who followed me in the introduction into the context and, after, checking my work. I stayed in her office, one of the Healthcare Direction Unit, and it permitted me to have a reference point for any doubt.
  In addition, the Data Unit office is adjacent and it permitted me to have the necessary information and materials for developing my reasonings.

- Focused meetings with operators of Warehouse and Pharmacy. Once the work began and some issues have been collected, there have been organized specific meetings with operators in Pharmacy and Warehouse where I explained the Digital Twin approach and we reasoned together on the problems, understanding whether a support based on DTs could be a solution or not.

- Focused meetings with the Coordinator of Pharmacy technicians. Similarly, some meetings have been organized with the Coordinator of Pharmacy technicians to have a wider overview of the problems, and situations and a critical perspective about the entire process flow.
  In these moments the main problems have been discussed, understanding whether were relevant and whether were not.

- Studying of internal material (outcome of meeting about process evolution). Another critical part of the work has been studying the internal documents about the changes with CCCRN project. In particular the ones about the logistical process from the beginning (product order) to the delivery at the ward.

- Focused meeting for the development of the Machine Learning algorithm (chapter 7). The development of the algorithm required some meetings with the Data Unit Manager to improve the work and understand better the data.

These have been all the activities done in support of the contribution of this thesis.

This section introduced the analysis work and supports the following parts, by guaranteeing the source of information and reasonings. As explained in the chapter about Digital Twin, the strength of this approach is due to the ability to represent properly the physical objects/entities. These methodologies ensure the quality of the following analysis and model proposed.

5.2 Comparison IRST as-is with IRST to-be

The activities of the IRST Centralize Compounding Centre , located near of the IRST IRCCS Institute, will take over all production activities of oncology therapies set up and radio drugs, both for radiometabolic therapies and diagnostics, of the territorial scope of AUSL Romagna. It will therefore have to produce for the IRST IRCCS in Meldola and for the departments of the AUSL Romagna, where chemotherapy drugs are administered (UO. Oncology, UO. Hematology, UO. Nuclear Medicine, UO. Surgery, UO. Ophthalmology, etc.). The following describes some differences between IRST's current and future situation identified as of greatest interest and relevance to the discussion of this thesis. They do not represent a complete description of the future processes, but some useful information for the comprehension of the work.

	IRST As-is	**IRST To-be**
Production volumes	X	2,3*X
Hospitals that Pharmacy will serve (with distance)	• Meldola (0 km) • Forlì (12 km) • Cesena (24 km)	• Meldola (0 km) • Forlì (12 km) • Cesena (24 km) • Ravenna (39 km) • Faenza (32 km) • Lugo (48 km) • Rimini (67 km) • Cattolica (82 km) • Novafeltria (51 km)
Expected travels per week (and per days)	• Meldola: 20 (4/day for 5 days) • Forlì: 15 (3/day for 5 days) • Cesena: 15 (3/day for 5 days)	• Meldola: 20 (4/day for 5 days) • Forlì: 15 (3/day for 5 days) • Cesena: 15 (3/day for 5 days) • Ravenna: 18 (3/day for 6 days) • Faenza: 15 (3/day for 5 days) • Lugo: 15 (3/day for 5 days) • Rimini: 15 (3/day for 5 days) • Cattolica: 5 (1/day for 5 days) • Novafeltria: 5 (1/day for 5 days) Considering the expected plannings of routes, the amount of travels (intended out of hospital, so excluding the inner ones toward Meldola wards) will increase of almost 3 times: from 6-7 (considering extra-ordinary travels) to 20

Continuation of Table 5.1		
	IRST As-is	**IRST To-be**
Warehouses / materials storage	• IRST (Via Maroncelli, Meldola) • Kanban near to Robot	• IRST (Via Maroncelli, Meldola) • CCC (Via Montanari, Meldola) • External warehouse (Via Roma, Meldola) • Kanban near to Robot and Manual production location

Continuation of Table 5.1		
	IRST As-is	**IRST To-be**
Logistical process of oncological therapy (no experimental therapies)	• Orders from Pievesistina and private companies (2 times/week). • Delivery in IRST (via Maroncelli). • Upload of products on software for warehouse management. • Registration and placement of products inside the cabinets. (after the confirmation of therapy and related picking list 24h before administration) • Picking list processing (collection of materials listed). • Delivery of materials from warehouse to laboratory (by passing through the wall that divides them).	• Orders from Pievesistina and private companies (2 times/week). • Delivery in via Roma. • Upload of products on software for warehouse management. • Upload of products into unitary dose machine. • Split of materials into: – Hot materials: direct to high-tech cabinets in via Roma – Cold materials: direct to high-tech cabinet in CCC – Consumable product: normal cabinets in Via Roma (after the confirmation of therapy and related picking list 48h before administration) • Picking list processing (collection of materials listed). • Order of materials for the following 48h from Via Roma to laboratory (by a van). • Use of materials stored in the warehouse in CCC and the Kanban near to Robot and Manual production. • Fulfillment of CCC warehouse and Kanban with materials arrived from Via Roma. • Automatic re-order from Pievesistina.

Continuation of Table 5.1		
	IRST As-is	**IRST To-be**
	(This final part of the Logistical process of oncological therapy remains the same) • Production and verification of the prepared drug. • Wrapping of therapy (prepared drug and other components). • Upload on software system and insert in shipping list. • Delivery on destination ward. • Check of correct transfer. • Therapy administration.	

Table 5.1: Comparison IRST As-Is and To-Be in operative terms.

These are the current conditions and the expected ones for the project. For understand better the future condition of IRST and some elements discussed above, it is necessary to provide some additional considerations:

- Twice a week the IRST LFO (Laboratory for Oncological Pharmacy) will send to Pievesestina (AUSL warehouse) an order of drugs, consumables and medical devices. These orders, unlike today, will be processed semi-automatically by the warehouse IRST pharmacy with the support of the electronic medical record. Based on the following week's oncology therapy reservations, in fact, orders will be processed as a centralized warehouse.

  Then, talking in operational terms, the IRST oncologist/haematologist and AUSL physician, during the examination and at the time when he/she perceives the need to proceed with oncohematology therapy, proposes to the patient a scheme of therapy and enters the therapy scheme in planning (for outpatient Day Hospital/day service) or in inpatient note (for ordinary regimen). Therapies and patterns are then later confirmed closely following hematochemicals examinations. The planning and admission list are the tools for planning therapies.

  Each patient is placed on the basis of the specific therapy schedule in the inpatient regimen appropriate. Each therapy scheme clearly codes at the computerized chart level the consumables, medical devices, and oncologic and ancillary drugs necessary for the proper setting up of the therapy. Therefore, based on the schedule (admission note and IRST and AUSL planning), the stock requirements are generated automatically for the following week. Based on this mechanism, with the stock already in the warehouse and the minimum and maximum stock coded for each item: the IRST pharmacy warehouse will generate an order for the AUSL warehouse. Once the order is processed, twice a week IRST will receive the materials. For this purpose, a suitable space has been identified for the IRST warehouse where it can manage the incoming logistics flows.

- Regarding the ancillary drug, whether at room temperature or refrigerated temperature, the unit dose of the blisters/phials of the ancillary drug will be produced. Automated equipment will be installed in the warehouse capable of creating for each pill/phial a single-dose package (called "ring", since they will be kept together by a plastic ring) with tracking of all necessary information (identification code, lot and expiration, drug name, etc.). Following the creation of the single dose of these drugs, they will then be stored in special cabinets in accordance with the correct storage temperature. On the day of patient therapy production, automatically based on the pick list processed by the pharmacist in the laboratory, the single-dose storage cabinet will process the ring of the patient, thereby tying the drug information to the individual patient. In this way in therapy packaging will be associated with the oncology set-up, the ring patient ring of ancillary therapy and the dilution devices. Each therapy will therefore be delivered complete and fully tracked to the departments of administration.

- The organization of travels is an important point for the impact of this project, and properly planning them allows to provide support to every hospital.

  In the first stage, it is assumed that there will be a single travel per destination but further developments for grouping more travels in a single delivery are in progress (e.g. Forlì-Faenza, Cesena-Novafeltria, Ravenna-Lugo and Rimini-Cattolica). A relevant point to consider here is the therapy's condition during travel: higher distance requires more accurate control of the condition inside the mean since the therapy is fragile in front of temperature variations. Considering the single-travel solution, the co-presence of expected deliveries at the same time is unavoidable since all the therapy administration services have approximately the same opening hours, and an attempt was made about the analysis of dispatches and their consistency. Starting with average daily set-ups (estimating 5 working days per week and taking into consideration the historical number of annual set-ups), a distri-

AVG therapies	Destination	07:30	08:00	09:30	10:00	10:30	12:00	12:30	13:00	14:00	16:00
129	MELDOLA		52		26		26			26	
40	FORLì	16				12			12		
60	CESENA	24			18				18		
50	RAVENNA	20		15				15			
42	FAENZA	17		13				13			
28	LUGO	11		8				8			
90	RIMINI	36				27			27		
17	CATTOLICA										17
8	NOVAFELTRIA		8								
464	**Tot. therapies**	**124**	**60**	**36**	**44**	**39**	**26**	**36**	**57**	**26**	**17**

Figure 5.1: The scheduling of therapies delivering system.

bution of set-ups per travel was assumed, where the first travel of the day for each location was planned with more therapies shipped than the other shipments, except for Cattolica and Novafeltria where it is also the only one. This is because, exactly as is the case today for IRST travels, it is assumed that therapies with greater therapies with greater stability and prepared the previous afternoon.

This is the project on which the internship has worked. The "To-be" side description (and related considerations) are the goal for the future, followed by a plan to build the necessary infrastructure, that is evolving in the last period. The internship project places as support of these mechanisms and aims to integrate them within the operations and way of working.

To conclude, it's important to emphasize the coherence of the project with the IRST's values: the approach is patient-centred since the operations are organized to provide the best assistance to patients, reaching a high-quality level for all citizens of Romagna. This collaboration between IRST and AUSL is mean to provide a universal and equal service to everyone that reaches them in their hospital, by guaranteeing efficiency, and effectiveness through an organization that aims to optimize the opportunity for every patient. Many elements described will be recalled in the following pages and they are useful to comprehend the other reasonings.

The following section looks into the questions analyzed during the internship period by exploring the effects considered in addressing the challenges presented above.

5.3 Process flow

The work of internship started by analyzing the overall process of production of therapy that will take place when the CCCRN project begins, to track a line among the internal operations and detect the relevant moment to trace. It has been possible thanks to the study of documents, periodic meetings with Healthcare Direction Unit managers and direct exploration with personnel involved in the processes.

As described in chapter 2, IRST is focused on taking care of oncological patients. The process in consideration treats the production of therapies that allow to fight cancer. The medical procedure, here called "therapy cycles" or "cycles of therapy", is composed of periodical administration of a certain therapy, called here 'therapy treatment'. Here the term 'therapy' is used to refer to the group of medicines that is going to be inoculated to the Patient during the Therapy treatment, where it is administered the 'oncological therapy' (part of therapy produced by IRST), and in the period after the treatment, when the patient swallows the ancillary drugs. This distinction is relevant for comprehension, and many clarifications of the terms are accessible in the glossary presented with the model proposal (table 6.14).

However, the process of production begins only when the therapy needs to be produced. It means that whenever IRST have the certainty (out of unexpected events) that a patient will come on a day to receive a defined therapy, the production process can start. Here it is considered the ordinary condition that is executed in many moments of the day for each centre.

Since in this study, the interest is on detecting the factors that affect the process, this has been considered also the process before. To represent the steps are used enumerated macro-groups starting by zero:

0. **The initial condition**. It is the one where the disease and the therapy to produce are known, so all the necessary analysis have been executed and the following steps are scheduled for the therapy administration.

   Before any administration, it is planned to execute a blood test that verifies the health condition of the patient. It is not an easy moment for the organism and a guarantee is needed, as better described in the section chapter 7.

1. **The blood test execution**. The patient has come to the hospital (IRST or the one where he is in charge since IRST is responsible only for therapy production) and the exam has been executed.

2. **Delivery of blood test**. The examination of blood tests in Romagna is executed in a centre located at Pievesistina. The transportation is not independent for each centre, instead, they are organized for delivering the tests in

a place and send a single means of transport, to reduce the travel. Once the blood tests are delivered, they are analyzed and they make the results available for the hospital responsible of care and for IRST that have to produce it.

3. **Confirmation of therapy**. Once the outcome received is 'positive', intended as good for authorizing the operations, it is required to receive a confirmation by the doctor who has the patients in charge.

   Whenever the outcomes are negative, the patients are scheduled to come back in the next period.

4. **Confirmation of picking list**. When all the therapies have been confirmed, they are uploaded on the web application that traduces them into the quantity needed to extract from the warehouse for producing them. It is called a 'picking list' and it must be confirmed by the pharmacist of IRST.

5. **Picking operations**. Given the list, all the picking procedures from the warehouse begin. The spaces are organized to have the warehouse near the Pharmacy to have a really short movement of products. An important improvement in the CCCRN project is the introduction of a robot that handles singular doses: receive the blister pack of the medicine and divide it into doses, then provide the medicines requested once the order is received. This system works only for pre-made medicines that do not require further work to be prepared.

   A further remark should be made to say that the handling procedures of products are done in compliance with regulations, by sanitizing the material before bringing it within the Pharmacy.

6. **Production of therapies**. Once the products have been delivered to the Pharmacy the production procedures of 'oncological therapies'. They are mostly executed automatically by robots and they are organized to maximize their usage.

7. **Therapy setting up**. Therapies are usually composed of a mixture of ancillary drugs and oncological therapy. After production, they are put together (since they are part of the therapy) to be delivered to the destination ward.

8. **Confirmation of therapy**. the therapies are checked after production in order to guarantee a certain trustworthiness of the process.

9. **Wrapping of therapy and division for destination**. Therapies are finally prepared for delivery procedures and then divided per destination.

The possible directions to take are the ones described in the table 5.1 and this separation helps to organize the transfer.

10. **Delivery of therapy**. Once the packages have been loaded on the means of transportation or the internal system of drug transportation (for the therapies to be administered in IRST), they proceed in the travel up to the destination ward, where the operations of the Pharmacy ends.

These are the overall steps macro-grouped in logical terms, but in each point are involved specific operations that have to be executed in a precise way or involve external actors (eg. therapy delivery that is done by a partner). Some further considerations to do in this description: all these steps are organized in working shifts, so the steps are the same but repeated more times in a day. The terms have been used in plural since more therapies are produced in parallel. In general, these procedures are done one day before administration for the patient scheduled on the first turn of the morning, then on the same day. This question is relevant for the case discussed in chapter 7.

The flow of the entire process has been analyzed to comprehend the reality in all its relationships, as well it has also been helpful for the detection of the issues. Looking them over the flow helps to understand the relations and impacts that they have. The following chapters are focused on the description of the criticalities detected, as one of the core elements of this thesis contribution.

5.4 Critical Processes

5.4.1 Tracking the position of blood tests

Description of the situation The blood tests to authorize the administration of a therapy are executed in Meldola and they have to be analysed in the laboratory of AUSL at Pievesisitina. The travels to bring these blood tests are organized to collect the samples from multiple hospitals and make one single trip toward the laboratory. For this reason, the blood tests coming from Meldola are directed to the Hospital of Forlì, where they are moved to another means of travel that will bring them to the laboratory, with many other blood tests. This process works by a strict coordination between actors, and one or more issues may affect the organization. As a consequence, the blood tests from Meldola require a specific delivery to the Pievesistina laboratory, having in this way two shipments at short distances one from the other and an extra-travel to pay.

Critical information The significant information is what allows coordination among all the actors when an issue (or more) occurs, such as the state of the process to move the blood test and the expected time of arrival.

E.g. when there is a delay in the execution of a blood test for any cause. In this situation, the transportation from Forlì to Pievesistina should be alerted of this issue (or simply get access to the information about this travel) to wait the time required for receiving the missing blood tests.

Which will be the effects on sustainability factors The impact of this situation on sustainability would concern:

- Reduction of pollution caused by transportation. Better coordination would mean a high possibility of avoiding useless transportation.
- Reduction of the workload of operators. The Travel operators to access the same information nowadays require way more time.
- Increase of employee engagement. Providing a simplification at job for Travel operators is an opportunity to increase their engagement at work.

5.4.2 Predicting the consumption of active ingredients

Description of the situation In the IRST warehouse (WH), the ordering operations have been based, up to now, on human decisions and expertise. It means that they are not supported by any type of system that supports consumption prediction. So, a Pharmacy operator on certain days of the week take up the quantities present in the WH (by inventory) and set the orders, based on the period of the year, trend and many other assumptions related to its experience.

The relevance of this case is due to the increase in workload volume (table 5.1). The ordering operations will change a lot and it will be hard to manage following the rule used before, and the errors and waste, if observed in percentage, may become too heavy.

The quantity of products stocked in the warehouse can be defined as crucial for 3 main reasons:

- They have to be enough for all the patients (the out-of-stock is not a possibility).
- Wasting them would mean wasting considerable resources that could be invested elsewhere for the cure of patients.
- The drugs may have high commercial value that can affect strongly on the financial document (pending the financial results on one side or the other).

So, the goal of the management is to keep the value of medicines stocked and the waste as low as possible but enough for every patient (and considering that some extraordinary conditions may occur).

Then, a clarification is necessary to be defined: the medicines provided are not managed with the product name, since they differ from corresponding medicines, but it is based on active ingredients, the component that determines the healing action (that is legally valuable for distinguishing 2 different medicines). So, the orders are executed on active ingredients, even if the real objects ordered are obviously medicines.

Furthermore, a relevant point here (which emerged during the meetings) is the possible resistance of Pharmacy operators to the use of this support. They may not follow the order suggestions provided since they may not trust eventual support. This must be taken in consideration for the solution design.

Recalling the previous critical process (section 5.4.5), it is easy to notice that they are related. As described, IRST aims to anticipate the blood tests and manage the production on more days, impacting in this way in ordering operations. Having the scheduled therapies 3 days before would permit ordering the precise products needed for them, moving the approach from a prediction to a simple number to precise and confirmed needs (a similar evolution from a 'Push' to a 'Pull' approach). These are two distinct conditions but, assuming the concretization of eventual support for Scheduling blood tests, the prediction relevance will decrease and the benefits of this case need to be re-shaped (as well as the investments).

Critical information The essential information in this case is the minimum quantity to have in stock for guaranteeing the cure of patients. This one may be obtained by crossing the following data:

- The quantity of products currently in stock.
- The orders of previous years.
- The number of therapies planned.
- The number of therapies confirmed.(eventually)
- The trend of the usage of active ingredients.
- The trend of growth of pathologies and related therapies.

There may be others and a discussion with WH experts is suggested to support as best the ordering procedures.

An essential knowledge that can impact strongly in this case is the availability of suppliers: the prediction may be the most accurate possible, but if suppliers cannot provide you the product is useless. For this reason, it is just mentioned the possibility of integrating the WH management systems as key operations in guaranteeing the cure to patients. In the IRST case, this integration may occur with AUSL, as the main supplier, and it could provide extremely useful data.

Which will be the effects on sustainability factors

- Reduction of waste. More precise orders mean low products wasted, caused by over-estimation.
- Reduction of extra travel for additional deliveries. On the other side, the underestimation is cause of extra-ordinary deliveries for having sufficient drugs, which are costs and sources of pollution.
- Financial benefits due to the better results of financial statements. Having better results has an impact on stakeholders, bringing an increase in trust in IRST management.

5.4.3 Managing the products within different warehouses (WHs)

Description of the situation As said in the section 2.4, IRST is facing a strong change, that regards also the number of warehouses for managing the increase of products to manage. From a single place of stocks, there will be 3 not directly dislocated in the area where one is adjacent to the Pharmacy, one is in IRST (with all the medicines for the hospital activities) and another is external at Via Roma, that receives the products from outside for providing the first two. The point is that this condition is going to bring some complexities in managing the products to deliver for production, so for the provision of the necessary products to the WH near to Pharmacy (within the CCC building). It means managing the necessities daily and scheduling the transportation of the missing products.

In addition, a further necessity that has been collected and that is relevant to be included here since it concerns the operations of inventory: they are done manually since the two IT management systems in action (for WH management) are not able to trace properly all the movements of products inside and outside. So, once per month, the WH operators are required to spend many hours verifying the number of products and the conformity with the one registered. It happens because the 2 software for managing WH activities are not properly integrated.

In general, it is clear the necessity of having an overview of what is contained in each WH, the transportation between them and support to manage all the complexities related to this new condition. Then, from the meetings, there have emerged the following necessities:

- The awareness about a product's availability for the following hours or days. In other words, they would be interested to know if there is any procurement order planned for the next period, and getting this information could be particularly hard with 3 dislocated WHs.
- An automatic alert when the planned therapies require a certain amount of products that are not present in the WH in CCC, and it is necessary to organize extra-procurement orders.
- An automatic alert when a certain product is going to be retired for any reason, with its position (eg. problems of a specific batch).

This last point is just managed, obviously, but it can be improved in efficiency.

Critical information The relevant knowledge in the situation presented is provided by:

- The quantity of stored products.
- The necessity of certain products in front of expected workload, that needs to be translated into internal procurement order (between 3 WHs).

As well, additional value can be provided by alerting in the following situations:

- About the planning of Procurement orders, the system could be able to recognize autonomously the necessity of extra orders and may generate autonomously the Procurement order with the necessary quantities.
- About the retirement of certain products, the system could be able to track the position of all products regarding this issue and support the process of collection of them.

Another crucial piece of information can come from the IRST suppliers in each case when a procurement order faces an issue. Here the question becomes complex and out of the scope, but it is interesting to cite the enormous benefits there may be if the WH management system would include the data about WHs and orders of AUSL, which is the main supplier of products for IRST. Making it would mean predicting with sufficient time the re-order of products and managing very easily any issue that may occur in this process.

Which will be the effects on sustainability factors The impact of this situation on sustainability would concern:

- Minimization of deliveries and reduction of extra-ordinary travels. A reduction in transportation is always a benefit in ecological and economic terms.

- An improvement of the working conditions of Pharmacy operators. Supporting them in their operations means enhancing their working conditions, which could be an advantage for their engagement and for saving operational costs.

- Reduction of production delays. Having a holistic view of the situation permits to manage better the production and avoids delays, with consequences for patients and employees.

5.4.4 Predicting the answer of the system in front of specific working conditions

Description of the situation IRST, as any other hospital, is a very complex environment where the working flows are related and they depend on a large number of factors, and consequently are hard to predict and comprehend in their entirety. The perfect example of this condition is given by the production process of the Pharmacy: it is a flow that depends on the therapies that need to be prepared, which in turn are due to the patient's diseases and their condition (section 5.4.5), then it depends by the regulation for the preparation (in compliance with the authorities direction) with the workload and the workforce available in a certain moment.

IRST with the CCCRN project is facing a drastic change, where the previous flows are overturned, the provision systems are changed, and the workload is around doubled. From the meetings, it has emerged the necessity to know with a certain precision the time required to execute the production operations. It may be important for planning activities, providing a reliable service to patients or being respectful to employees. In a similar case, the complexity may be too high to predict the overall production time because the connections between elements are intricated.

From another perspective, IRST is constantly interested to know how to improve its processes in front of specific necessities. For instance, guaranteeing the quality and efficiency of the production process while facing a new trend or modifying certain operations. As before, testing different operations may be particularly hard to estimate. In other words, they are interested in understanding which will be the behaviour of the system in a precise condition. The situation is the same as the CCCRN change but moved in ordinary conditions.

Then, another need arose in the discussions about the possibility of having extreme workload conditions where IRST is not able to satisfy all the demands. Providing a real-time alert of an unsustainable situation that requires to be managed can be the key in these cases. It may happen as a consequence of unexpected issues or any strong delay in previous steps.

Critical information Considering the needs presented above, the critical information is the time required from the process to finish the workload in front of certain conditions.

It can be obtained by integrating all the relevant data that influence it. These factors may be:

- The type of therapy.
- The production type (manual or robotic).
- The procedures to follow for guaranteeing security (and being compliant with regulation).
- The workforce available (eg. the number of employees).
- The availability of products (recalling the needs discussed in section 5.4.3).

Ideally, these can be the arguments for evaluating the overall time required for the development.

Up to now, the consideration can be limited to time but further developments focused on a sustainable perspective can extend it to a general 'resources to spend', including other dimensions of interest (eg. workforce, energy, etc.).

Which will be the effects on sustainability factors The impact of this situation on sustainability would concern:

- Improvement of working conditions of Pharmacy operators. The possibility of monitoring and enhancing production processes may have a direct impact on Pharmacy operators and working conditions. The consequence still here can be higher engagement, with consequences on productivity.
- Improving efficiency in production. Having similar support implies the opportunity to be more productive, which means saving operational costs.

- Guaranteeing the quality of cure. Having the opportunity to be alerted whenever an unsustainable condition arises, means having the possibility to solve issues or reduce the impacts, at least, to guarantee a universal cure.
- Supporting a sustainable development in all dimensions. Testing different conditions would permit the evaluation of the impact of new situations under the different dimensions considered relevant for sustainable development. It is quite general and involves the possibility of including many perspectives.

5.4.5 Scheduling of blood tests

Description of the situation In the process explained (about therapy production) a discriminant of the execution of the entire process is the outcome of the blood test analysis.

To describe the context is necessary to start with the overall comprehension of the therapy's execution procedures. The therapies work by cycles and each cycle administration must be authorized by a blood test that verifies the patient's condition. The ordinary situation starts with a prescription of therapy done by a doctor, then the Front-office operators schedule the days of administration (following the prescriptions) and then set the date for the first blood test following some schemas, used for many years, that plan it 1 day before therapy treatment (out of therapies planned on Monday). Once the outcome of the blood test authorizes the administration (and the doctor provides one last confirmation), the Pharmacy can start production with the products available (and planned) in the warehouse.

As the first step for understanding the criticality, it proceeds to look at the impacts. Having the confirmation for the treatment a single day before means that the Pharmacy can manage the production only in that reduced time, and considering the expected increase of workload (table 5.1) there is no certainty about the real ability to conclude the production on time. Similarly, this condition does not allow management of the orders on confirmed patients, instead must be based on a prediction of how many positive blood tests there will be.

From another perspective, each 'negative' blood test (the ones that block the treatment) represents a set of consequences. In sustainable terms, it has economic, social and ecological impacts. Looking at the current data, 20% of cases do the blood test more than once before receiving the therapy. So, reducing this rate can have multiple benefits.

For all these reasons, the Healthcare Direction Unit is interested in extending this period to 3 days, to have the opportunity to spread the workload, ordering based on confirmed therapies and improving the efficiency of the Pharmacy. In parallel, they want to reduce the rate of negative tests by improving the scheduling procedures used now (the old schemas).

This process is deeply discussed in the chapter 7 where is possible to find more detailed information.

Critical information The key information in this case is the outcome of the blood test analysis. It encloses the meaning in operative terms, that is the confirmation for production. And jointly, the meaning of social dimension is the authorization to proceed with cure.

Ideally, the goal would be to have the certainty of this information, but it is not possible, so the real target is having it with a sufficient degree of reliability.

Which will be the effects on sustainability factors

- Reduction of useless travels.

  Decreasing the rate of negative response to blood test means also reducing the travels of patients to reach the hospital.

- Reduction of patient disease.

  A 'negative' blood test also has an impact on the inconvenience caused to the patient and his family in managing the situation. Avoiding these circumstances can also be an improvement in this respect.

- Reduction of material wasted.

  Making a blood test requires obviously medical materials, which becomes unnecessary when the blood test appears useless (negative responses).

- Waste reduction in WH.

  Moving the blood test 3 days before (instead of 1)permits them to plan the orders on the specific therapies confirmed, so avoiding the prediction work for planning how many patients will be able to receive the therapy. In this way, we are removing the uncertainty factor in orders and it may mean avoiding products wasted (whenever the patients are not ready).

- Savings in operational costs.

  The execution of blood tests and all operations around is done by operators and nurses who spend their working time in this way. Reducing the cases of unnecessary tests means avoiding this working time, and related costs forhospitalsl.

- Reduction of extra-travels for ordering missing products.

As a consequence of the prediction, it may happen that the products in warehouse appear to be insufficient. In these cases, some extra-travels can deliver the missing products but they mean high costs.

Better management in WH means reducing costs and pollution in this way.

5.4.6 Tracking the position of therapies

Description of the situation The idea at the base of CCCRN is that IRST Pharmacy will produce oncological therapies for itself and for AUSL hospitals. As described in the process above section 5.3, given the therapy's scheme they prepare and deliver it to the destination. It happens sometimes that therapy is directed to the wrong transportation (or stays at Meldola when it has to go elsewhere) and it is not delivered on time. The day after it is placed on the first possible transportation direct to the real destination for proceeding with the administration. This situation has heavy consequences on the patient who needs to return the day after, as well it is a missed cure for another patient that has not been scheduled in place of the first one.

The causes of this event are attributable to simple and unconscious errors. They may happen, but the consequences are considerable. A possible source of this error, especially in the future, could be the volume of workload. As repeated many times, this is going to increase and IRST is interested in solving this situation to avoid a missing satisfaction of the procurement defined by the agreement with AUSL. Talking about this collaboration, many actors of AUSL could be interested to know the status of travel, and the presence of eventual errors or delays, for organizing their work and operations.

Critical information In this case, the key information can be:

- What permits to avoid these mistakes, such as the recognition of the wrong destination before delivery.
- What permits to organize internal operations of involved actors (eg. Destination ward) as soon as possible.

Which will be the effects on sustainability factors The impact of this situation on sustainability would concern:

- Avoiding extra-travels. Any extra travel has an impact on pollution and costs.

- Reduction of patients' diseases. Any wrong delivery has a strong impact on patients and those around them.
- Reduction in the workload of operators. Also here, the possibility of reducing the work to do is considered as an opportunity to increase employee condition, with benefits on engagement and productivity.

Chapter conclusion Here end all the situations depicted as critical where an improvement in the prevision of CCCRN is necessary. As anticipated, they are the beginning for developing further the arguments. As it is the following chapter, where the proposal model is discussed in all its components.

Chapter 6

Solution proposal: a model of Digital Twins to track critical information from the process.

This chapter represents another large piece of the contribution made by this internship experience at IRST. Following the analysis of the therapy production process, in terms of its macro-steps and the specific situations to be improved in perspective of the beginning of the CCCRN project, there will be presented and schematically discussed the proposed Digital Twins model that could support IRST personnel in critical situations to be improved.

This model was conceived through the knowledge gathered in meetings with Pharmacy staff and developed in close contact with the co-supervisor. Given the circumstances of the internship, the aim has been to provide a potential proposal based on the criticalities from which the Healthcare Direction Unit and Pharmacy can start to delineate precisely the data to be collected to represent the actual assets. This crucial operation, to be carried out with domain experts, requires to be based on specific needs and reasonings about the overall context for reaching the goal of DTs, so representing assets in its essential value. And this is the value of the thesis' contribution.

The chapter is structured in the presentation of the model (section 6.1) with the description of the elements which compose it and the glossary of terms used (section 6.1.1), followed by the explanation of the ways in which the model can address critical processes (section 6.2).

6.1 Model proposal for therapy production process

The previous sections described the knowledge collected during the internship about IRST. The process has been crucial for understanding the relationships and the dynamics of the overall process, which made me able to gather part of the domain knowledge. On the other hand, the comprehension of issues provided the starting point for all the reasonings about Digital Twin: the needs. They have been the base for designing the DT structure presented here.

It is composed of a graphical illustration of elements and their relationships, with a detailed description of each of them and a glossary to clarify the terms used. Thereafter, it is discussed how this model can address the critical processes described (section 5.4).

The model presented below aspires to be a proposal to be used in future for developing DTs over all the relevant processes in IRST. It is a composition of multiple DTs (a DT Aggregate) that aim to be used as a middle stage between real objects and software agents (fig. 4.5), so creating the basement where to start for the development of these components able to extract the key knowledge depicted, and for being extended for gathering new potential one.

It is based on the ideas listed in the previous sections: the needs drove the choices and the representation tries to replicate the reality in the features considered as relevant (from the analysis). Similarly, the model aims to be a starting point that places in a cycle of continuous improvement and adaptation in front of new needs and necessities. Even if, we must be aware that the meetings held may not be sufficient to gather all the feedback along the various stages of development, so further discussions with domain experts would be necessary before extending it.

The fig. 6.1 shows the strategic assets considered relevant to be represented in a virtual version. The core one is the Therapy, for its central role in the process of interest, where all the others are directly or indirectly related. Their presence has been dependent on the necessities around each of them.

It may be for accessing in real time to the information. It is the case of Travel: multiple actors are potentially interested in knowing the state of a certain shipment (still in preparation, at IRST, in travel, etc.). Similar reasons are also for Warehouse DT, where many actors may be interested to know the availability of a certain product, and for Production batch, where many actors may be interested to know the progress status of a certain workload.

Otherwise, the reason to include certain elements is to track an asset in a precise format in relation to one or more other assets. It is the case of Therapy, where actors of different areas are interested to know different perspectives of the single object in relation to the other elements. On one side a pharmacist may be interested to know which are the scheduled therapies to prepare in the next working shift, so the connection of Therapy with the Drug to set-up and the Production batch may allow to estimate the processing time. On the other hand, the doctor of the destination ward (in another hospital) may be interested to know if the scheduled therapies are going to be delivered on time for internal reasons. The necessities may be many and the extendibility of this system can be the key to its success.

Just some further remarks about this section. First, the description here is done quickly because a better explanation is done in the following pages by outlining the goals for each DT. Then the model shows two particular connections:

- 'Extension relationship' between Drug, Drug to set-up and Pre-made Drug.

  This represents the extension concept of Object-oriented programming (OOP), which refers to a class's ability to inherit attributes and methods from another class, allowing the creation of a new, more specific or specialized class. Extension occurs through the concept of inheritance, where a child class inherits the characteristics of the parent class. In this case, the object Drug would contain some essential feature belonging to each typology of drug, shared between both of the types considered. So the properties of the Drug to set-up and the Pre-made Drug include also the ones of the Drug.

- Dotted connection.

  This one represents the optional presence of the relationships, where an element can be related to another as well as they can be separated.

  - Production batch, Robot and Manual preparation. In this specific case, the dotted connections mean that a precise Production batch can be prepared in a single way or both, but it depends on the situation.
  - Procurement order and IRST warehouse. Here the dotted connection is used to consider the cases when the procurement order has a different origin to the IRST warehouse, as the AUSL warehouse instead that are not managed here.

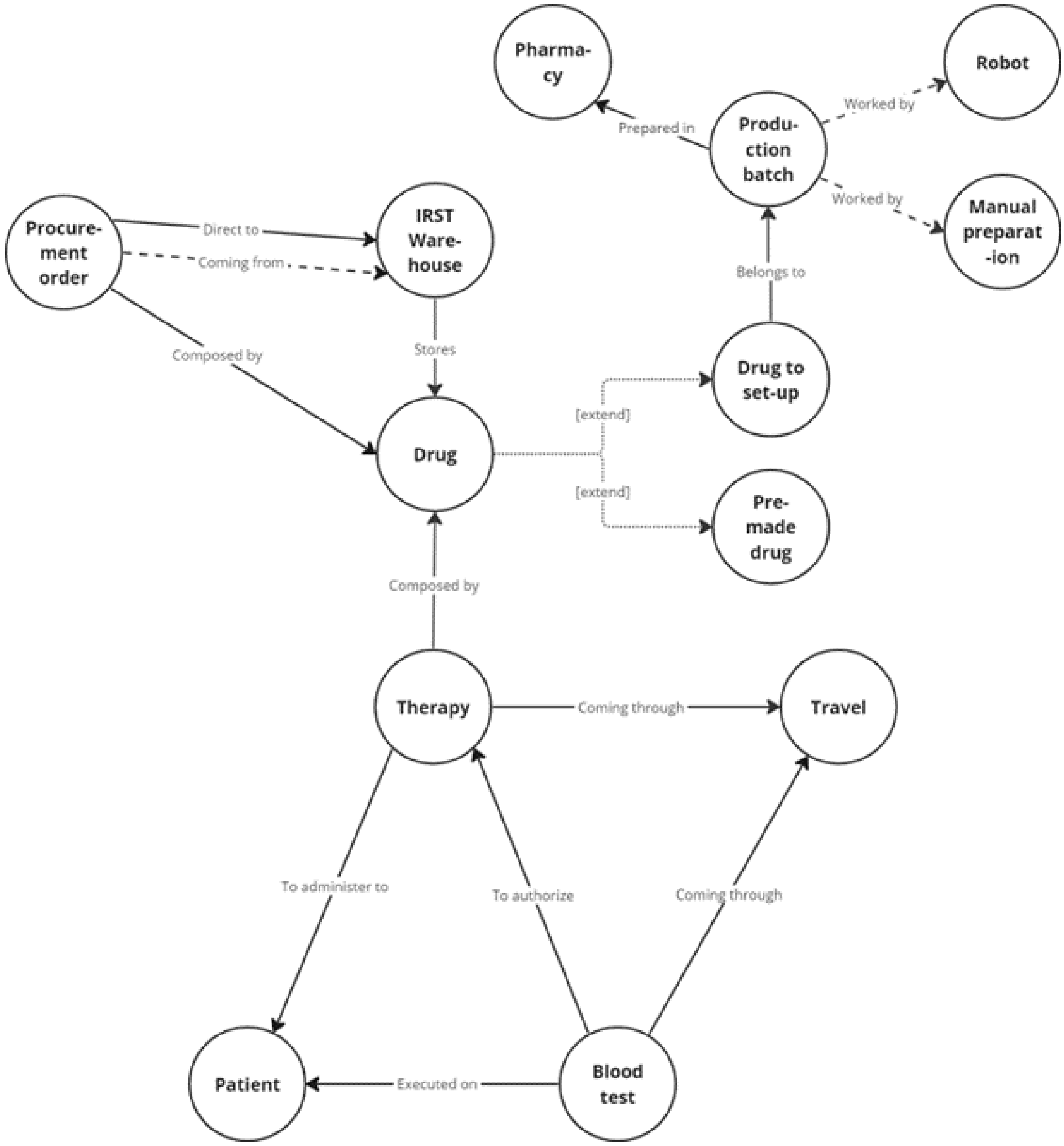

Figure 6.1: A graphical illustration of the DT model for Therapy supply chain.

6.1.1 Digital Twins components and glossary

After the model presentation, each Digital Twin is presented in a tabular format showing (or recalling) a definition of the objects considered, some properties that it should include in order to provide the critical information necessary (derived from the description of critical processes), the goals for tracking the data concerning that asset and some of the possible and relevant events that can be generated (that contain certain information).

Additionally, below is provided a glossary of the terms used for the development. It is built for permitting to each actor involved to understand and be sure to communicate properly. Its presence confirms the 'domain-driven' approach discussed since it is based on the logic of Ubiquitous language and appears fundamental in a context and project with people with very far backgrounds.

Therapy	
Definition	Group of Drug that is going to be inoculated to the patient during the therapy treatment and in the period after the treatment (the ancillary drugs).
Properties	• ID • State [in preparation, prepared, delivering, to retire, delivered at hospital, delivered at ward, delivered, wrong destination, etc.] • Destination • DateTime of finished preparation • DateTime of arrival • Stability terms • Expected preparation time • Actual preparation time • Expected provision time
Goals	• Track the position of therapy and delivery state • Furnish the expected time to provide the Therapy • Notificate issues in delay of provision • Track the Therapy in preparations process
Events generated	• Notification for issue in provision

Table 6.1: Therapy Digital Twin

Travel	
Definition	procedure of transportation of an asset (Blood test or Therapy) from Meldola to the Destination
Properties	• ID • State [in preparation, prepared, Travelling, At destination] • Destination • Last stop [Meldola, (Middle-stop1), (Middle-stop2), etc.] • Temperature min guaranteed • Expected duration (time) • Actual duration (time, [nothing since it is proceeding]) • All the information regarding the logic of the travels (stops, order, route, etc.)
Goals	• Give access to the position of Therapy • Track the time required to deliver an asset • Coordinate multiple travels used to bring blood tests to Pievesisistina, by giving access to the information about the delivery of blood tests (for those waiting for this travel to deliver other blood tests) • Simulate the effects of changing the travels (e.g., changing the hour, changing the stops, and the order of deliveries) • Track the delivery performances to each Hospital (for Therapy) • Track the number of patients and the organization of travels
Events generated	• Wrong direction of Therapy • Therapy arrived

Table 6.2: Travel Digital Twin

Blood test	
Definition	Sample of blood that is going to be examined by the laboratory to authorize the Therapy administration.
Properties	• ID • State [Executed, Travelling, delivered at Pievesistina, Analyzed, etc.] • Last stop [Meldola, Forlì, etc.] • Expected arrival (time) • Result [null, Positive, Negative]
Goals	• Track the blood test of patients • Track the position of blood tests in transit to Pievesistina • Simulate the response of the system in front of certain blood tests
Events generated	...

Table 6.3: Blood test Digital Twin

Patient	
Definition	Person took charge by the Oncological network of Romagna.
Properties	• ID • Age • Sex • Cancer code
Goals	• Track the treatments and history of the patient • Evaluate his/her response to therapy administration • Simulate the response of the system in front of certain blood tests
Events generated	...

Table 6.4: Patient Digital Twin

IRST Warehouse	
Definition	Building used for storing medicines. It can be the internal warehouse (WH) of CCC, Kanban near Robot, Kanban near the place for Manual production, WH in IRST or WH located at Via Roma
Properties	• Location [Via Roma, IRST, CCC, Kanban Robot, Kanban Manual production] • List of products (represented in the way IRST currently manages them)
Goals	• Provide real-time quantities stored inside to the operators of the pharmacy • Provide alert when the material is below a certain threshold
Events generated	• Warning for shortage of active ingredients

Table 6.5: Warehouse Digital Twin

Procurement order	
Definition	Order for the provision of materials between AUSL WH and IRST and among IRST WHs.
Properties	• State [To be prepared, In-preparation, Ready, Delivering, Arrived, etc.] • Type [For moving products between WHs, From AUSL] • Source [AUSL, IRST, CCC, Via Roma, Kanban Robot, Kanban Manual production, external] • Destination [AUSL, IRST, CCC, Via Roma, Kanban Robot, Kanban Manual production, external] • Expected duration • DateTime of finished preparation • DateTime of arrival
Goals	• Manage the products over 3 WHs • Track the orders to ensure that an order has been taken • Receive alerts in front of missing provisions or any issues regarding the provision
Events generated	• Delivery in provision • Regulation changes • Any issue with provisions

Table 6.6: Procurement order Digital Twin

Drug	
Definition	Medicine or other substance which has a physiological effect when ingested or otherwise introduced into the body. It is distinguished in "Drug to set-up" and "Prepared drug".
Properties	• ID • Active ingredient • Quantity [pz, liter, g,] • Format [liquid, pill, etc.] • Batch1 • Batch2 • Expiring date • Relevant information for transport [max temperature, time spent, etc.] • Quality check
Goals	...
Events generated	...

Table 6.7: Drug Digital Twin

Drug to set-up	
Definition	Drug used to prepare with other components (by means of Robot or Manual production in the Pharmacy) the Oncological drug.
Properties	• (All the properties of Drug) • Expected preparation time • Expected provision time • Delivery timestamp
Goals	• Track the information about the drug (traceability) • Provide the expected time to provide it • Notification of expiration • (My idea) Track the usage of a drug to suggest the precise format (with precise quantity) to order • Tracking wastes
Events generated	• Notification of expiration • Notification for retirement of drugs

Table 6.8: Drug to set-up Digital Twin

Pre-made Drug	
Definition	Drug prepared by external actors (so no need to be produced or assembled) that can be taken by Patient autonomously.
Properties	• Expected provision time • Specific indications provided by the producer
Goals	• Track the information about the drug (traceability) • Provide the expected time to provide it • Notification of expiration • Tracking wastes
Events generated	• notification of expiration • notification for retirement of drugs

Table 6.9: Pre-made drug Digital Twin

Production batch	
Definition	Batch of production used to organize the work in the working shifts.
Properties	• ID • State [in preparation, prepared, etc.] • Expected preparation time • Actual preparation time (once it ended) • The security procedures to do (for being compliant with regulation)
Goals	• Provide the expected time for the provision. • Keep track of workload. • Provide data for analysis for improving efficiency.
Events generated	• notification of delay in provision

Table 6.10: Production batch Digital Twin

Robot production	
Definition	Preparation process done by a Robot, a device able to produce an Oncological drug by receiving the excipients. It works by receiving the drugs to compose and it stores the unused portion for further productions.
Properties	• State [Still to begin, In execution, Finished etc.] • Expected conclusion time • Quantities of products within the Robot
Goals	• track the activities in execution • track the usage and free-time • plan the operations considering its duration
Events generated	• Any issue in production

Table 6.11: Robot production Digital Twin

Manual production	
Definition	Preparation process executed manually by an operator.
Properties	• State [Still to begin, In execution, Finished etc.] • Pharmacy operator ID • % of workload remaining
Goals	• track the activities in execution • track the usage and free-time • plan the operations considering its duration • track the quantity of work done manually (e.g. for planning the hiring)
Events generated	• Any issue in production

Table 6.12: Manual production Digital Twin

Pharmacy	
Definition	Department of IRST that produces theapies by assembling the Drug to set-up.
Properties	• % of the current workload • Number of Pharmacy operators present. • % of the expected workload in the next work shifts
Goals	• Provide real-time workload in Pharmacy • Provide expected workload in the following work shift in the Pharmacy • Provide alert when a request of work exceeds the workload capacity
Events generated	• Warning for exceeding workload

Table 6.13: Pharmacy Digital Twin

These elements are the ones designed to compose a solution proposal based on Digital twins. Each of them can be considered an independent DT, where the properties, goals, events and relationships are based on the critical processes that emerged (section 5.4). In detail, the description of these elements is due to the relevance that those assets have for IRST in facing those situations. These reasonings about how the model can support them are presented in the following chapter, where those conditions are recalled to show how the model of DTs proposed can support those situations.

The representation of the model and its components may lead one to think that they are simplifications or not significant descriptions for the context. Instead, it is the outcome of the analysis, with critical processes. These two elements enclose all the knowledge gathered during the internship, from the explanations of domain experts about how the internal operations work, and any discussion about the issues in current activities or doubts about future conditions. As well, they represent the reasonings executed from the comprehension of the situation and from the exploration of each condition.

As anticipated, this does not mean that is a definitive version, but it is a valuable starting point for including further reasonings about the process considered or for extending the DT with other operations.

In the following section, it will be discussed how this model proposal can support the critical processes, by showing the reasonings behind the choices about elements presented above.

Therapy	Group of Drug that is going to be inoculated to Patient during the Therapy treatment and in the period after the treatment (the ancillary drugs).
Therapy treatment	Single treatment, intended as inoculation of a drug, in the cyclcal process used to fight the disease. It has been used as synonym of **Therapy administration**.
Patient	Person who is going to receive the Therapy.
Drug	Medicine or other substance which has a physiological effect when ingested or otherwise introduced into the body. It is distinguished in ”Drug to set-up” and ”Prepared drug”
Oncological drug	Drug incoluated during Therapy treatment to fight the cancer disease.
Ancillary drug	Drug to support the Therapy treatment and the side effects of Oncological drugs.
Drug to set-up	Drug used to prepare with other components (by means of Robot or Manual production in the Pharmacy) the Oncological drug.
Pre-made drug	Drug prepared by external actors (so no need to be produced or assembled) that can be took by Patient autonomously.
Pharmacy	Department in IRST committed for the production and assembly of Therapy
Production batch	Batch of production used to organize the work in Pharmacy.
Robot	Device able to produce an Oncological drug by receiving the excipients.
Manual production	Preparation process of Oncological drug done manually by an operator.
Travel	Transportation of the relevant assets considered in this context: Therapy, Blood test and Drug
Blood test	Sample of blood that is going to be examined by the laboratory.
Laboratory	Place where the Blood test is examined to extract the relevant information for the specific purpose.
Destination	Destination place of the assets considered (Blood test, Therapy or Drug).
Ward	Specific part of the hospital where the therapy is going to be inoculated
Active ingredient	Medicine’s component that determine its healing action and that distinguish medicines with distinct healing properties.
Travel operator	Operator paid to move any Therapy, Blood test or Drug between the locations considered.
Front-office operator	Operator of IRST that manage the scheduling of Blood test for patients.
Pharmacy operator	IRST operator in charge of executing the inventory and making the orders of products.
Picking list	List of drugs to take from warehouses to make a therapy
Therapy set-up process	Process executed in Pharmacy to assemble and produce the Therapy, starting form the picking process from the warehouse to the grouping of Therapy components.

Table 6.14: Glossary of terms used in the model proposal.

6.2 Improving Critical Processes

Below are described how the critical processes (section 5.4) can be improved using the model proposed. Based on it, this section aims to demonstrate how a DTs-based solution can answer the needs that emerged in the analysis.
These are presented by describing the role that DT should have in these situations, a very general description of the operations that should occur to support them and, starting from the knowledge collected and the sustainable factors included, a list of KPIs that could be used to measure the improvements. This last section has been considered since the definition of improvements in a certain situation is based on needs behind it, so it is relevant to be discussed in this moment.

Critical process	Track the position of blood tests.
Role of the DT	Provision of real-time data about the status of blood test processes to Travel operators to permit optimal coordination and reduction of extra travels.
How the DT elements should work to answer to that question	• The Travel DT provide its status with an 'intelligent agent' that captures it and shares with (or makes it accessible) to the Travel operator. The instance of the Travel regarding the transportation of Blood tests should be created at the start of the working day and updated when relevant domain events occur. E.g. the car arrived at Meldola, the start of loading the car, the finished loading and the start the travel.
KPIs	• The number of extra travels from Meldola to Pievesistina. • The delay of deliveries (for all the cases when the blood tests of Meldola are waited).

Table 6.15: DT support to the critical process about tracking the position of blood tests (section 5.4.1).

Critical process	Predicting the consumption of active ingredients.
Role of the DT	A DT can support an intelligent agent with a data structure for building a model able to predict the future consumption of each active ingredient. Considering the possible resistance of personnel to eventual support, it is expected to provide a range in which the orders ca be done, and the implementation of the solution would consider the investment on certain activities required to encourage the use of digital support, demonstrating the real benefits (on the entire ecosystem) and the manoeuvre margin left to the own expertise. For this case, the agent is imagined to be a 'Prediction algorithm' based on certain data that allow to extract the critical information, that here is represented by the expected consumption (with a certain degree of reliability). For instance, whenever is needed to make the orders for the coming period, the Pharmacy operators could orders a certain quantity into the range provided by this algorithm, that receives the necessary data for its evaluation in a structured way by the DTs. At support of WoDT approach ([30]), the integration with AUSL orders management system can be extremely valuable by providing all the benefits of the 'extended value-chain', based on the idea of sharing data for improving the choices of direct stakeholders. Also here, reminding the case for Scheduling blood tests, all the benefits can downsized and the effort in building this supporting agent may be higher. So the investment appears to be unnecessary.
How the DT elements should work to answer to that question	• The IRST Warehouse DT provide the quantity stocked in real-time. • The Therapy DT provide: the therapies already scheduled to administer (confirmed by blood test and not) and the past therapies considered as relevant for the prediction. • The Procurement order DT provide the previous orders done for the active ingredient of interest. • The Patient DT provide the information about diseases to evaluate the trends. There may be many ways to make the prediction, as: 1. Based on the consumption without considering the sources. 2. Based on the consumptions and its sources (therapies and pathologies). For this reason, it is important to provide different information and it is useful to build a structure able to evolve and include other elements.
KPIs	• Number of extra-travels for additional deliveries. • Quantity and cost of medicines wasted. • Weight of unnecessary medicines on Financial statements.

Table 6.16: DT support to the critical process about Predicting consumptions (section 5.4.2).

<table>
<tr><td>Critical process</td><td>Managing the products within different warehouses (WHs)</td></tr>
<tr><td>Role of the DT</td><td>Support the management of the stocked products over the 3 warehouses by providing:
The overview of the quantities contained in each.
The internal procurement (between 3 WHs) order is to be done based on the work expected for the following days.
So, the support of DT is imagined as follows: whenever is needed to organize the products for the coming period, the Pharmacy operators could access a dedicated system that provides the suggested procurement orders considering the confirmed therapies, leaving a manoeuvre margin for the operators.
Together, an intelligent agent based on DT could generate an alert whenever the following situations occur:
Missing products for production. The system could be able to recognize autonomously the necessity of extra orders and may generate autonomously the Procurement order with the necessary quantities.
Retirement of certain products. The system could be able to track the position of all products regarding this issue and support the process for removal of them.
Also here, the WoDT approach ([30]) appears powerful if it is considered the integration with the AUSL orders management system. It would allow to extending the management of procurement orders also with the one of AUSL.</td></tr>
<tr><td>How the DT elements should work to answer to that question</td><td>The WH DT share the quantities of product and the products to retire.
The Therapy DT provide the therapies confirmed with the products necessary for the production.
The Procurement order DT share the existing orders (and it represents the outcome of planning activties).
In this case, an 'intelligent agent' could elaborate the data provided and generate the Procurement order DT able to satisfy the overall needs by combining all the data. Then it should wait to be confirmed by Pharmacy operators, who could modify it if needed, before becoming real.</td></tr>
<tr><td>KPIs</td><td>Number of travels for transport drugs between warehouses.
Waiting time for receiving a drug in Pharmacy.
Feedback from Pharmacy operators.</td></tr>
</table>

Table 6.17: DT support to the critical process about Managing WHs (section 5.4.3).

Critical process	Predicting the answer of the system in front of specific working conditions.
Role of the DT	Support an intelligent agent with the data structured by the DTs for: • Simulating the behaviour of the system represented with new conditions. • Giving the possibility to modify some elements to simulate new processes. • Monitoring in real time the workload in the programme and the available workforce. The first 2 situations have been previously called 'what if ' analysis, and they exploit the relationships (and related complexity) between assets for evaluating the behaviour in certain cases.
How the DT elements should work to answer to that question	• Production batch DT share the preparation time (considering the time needed for the Robot and Manual preparation for the planned therapies) with information about security procedures. • Robot DT share its capacity to be used for evaluating the production time and the quantities of products to plan a re-fill. • Manual preparation DT share the % of workforce to be used for evaluating the production time. • Therapies DT share the types of therapies to be used for evaluating their production time. • Pharmacy DT share the number of Pharmacy operators to be used for evaluating the available workforce (not only for manual production, but for the all operations around the physical production). All of this information can be combined to evaluate the overall production time. It could be done in terms of "time required", for therapies to be prepared, and "time available" for the workforce. An indication about the term 'share': here is intended the values in front of the conditions set (for simulations) or current condition (for real-time monitoring). For this case, it is reminded of the possibility of extending this opportunity for any factors in the assets considered as relevant, that would need to be tracked and joined with other DTs. Sill here the idea supports the concept of WoDT ([30]).
KPIs	• Number of extra working hours. • Number of alerts received (divided per causes/issues) • Feedback from Pharmacy operators. • Number of Therapies not produced on time. • Rate of usage of Robot and Manual production.

Table 6.18: DT support to the critical process about Managing WHs (section 5.4.4).

Critical process	Scheduling of blood tests.
Role of the DT	In this situation a support DTs based can provide the data structure to be used by an 'intelligent agent' that can extract knowledge to use in blood test scheduling. This is represented by the guarantee of receiving a positive result, by crossing the necessary data (that requires a deep medical discussion). An improvement in this sense can be supporting the detection of cases that is possible to anticipate, with a sufficient reliability, for spreading at most the production and orders. This idea fits with the opportunities provided by Machine learning, that allow to build models able to support the scheduling operations of Front-office operators in order to improve the number of "positive cases" and making the blood test as before as possible. Moreover, it guarantess a certain level of interpretability for opening the discussion of the model with domain experts (the doctors). This model can be based on the relevant data about patient and therapy that impact on his recovery time, and this question must deepen with doctors.
How the DT elements should work to answer to that question	• Patient DT provide the relevant data for evaluating the recovery time. • Therapy DT provide the relevant data for evaluating the recovery time, and the time used by old schemas for having a benchmark. These past data of the Patient and Therapy are the sources for the preparation of the model. Considering that these data grow day by day, it is expected to improve the classifier (periodically) with new data about Blood tests and Patient, that should be collected and should support it. .
KPIs	• Rate of negative blood tests. • Feedback from Patients. • Number of extra-working hours necessary to prepare the Therapies. • Rate of usage of Robot and Manual production. • Number of extra-travels.

Table 6.19: DT support to the critical process about scheduling the blood tests (section 5.4.5).

Critical process	Track the position of therapies.
Role of the DT	Provide real-time monitoring of transportation by sharing the relevant information about it, and supporting the preparative operations for travel to avoid mistakes, by tracking the events and alerting them when they occur. For instance, this second functionality can regard the van-charging operations. Basically, the DT should provide the tools to avoid mistakes (whenever possible) and show the information to permit humans to recognize when an issue (or more) occurs.
How the DT elements should work to answer to that question	• The Travel DT share its status, expected time of arrival. • The Therapy ID share its destination. The instance of the Travel regarding the transportation of Therapy should be created at the start of the working day and updated when relevant domain events occur. These are the same relevant events to share with the intelligent agent and eventually trigger an alert. E.g. the van arrived at Meldola, the start of van loading, finished van loading, start the travel, mid-stages in the travel, arrival.
KPIs	• The number of mistakes. • The number of extra-travels. • Feedback from destination wards. • Feedback from Pharmacy operator in charge of preparing therapies for travel.

Table 6.20: DT support to the critical process about Track the position of therapies (section 5.4.6).

Chapter 7

A data-driven model for Patient Digital Twins: practical example

In the previous sections have been presented the reasons for enhancing management operations by DT model, followed by the issues where this support could be implemented. Setting aside the development methodologies and the investments needed, the interest from a strategic perspective is to comprehend if the support provided by DTs is essential for extracting critical information. Is it really necessary to organize the data in a precise manner to make it? Also, is it necessary to invest resources for the analysis of the context and problems for supporting the design phase?

This is the driver of this example. Here it is examined one of the problems detected in the production process of therapy, by providing a proposal of a data-driven model that can improve the current condition of IRST without having the support of DTs and data organized in that manner. This model is developed by a Machine Learning algorithm based on the data stored by IRST that aims to support the scheduling operations of blood tests for authorizing the therapy (Critical process of Scheduling BT). The development of this proposal has been strongly supported by the Healthcare Direction Unit, which identified the improvements described as particularly valuable.

The examples is presented by the following structure: a description of the process in consideration (section 7.1), an explanation of the objectives set (section 7.2) with the methodologies adopted (section 7.3) for developing the algorithm, followed by a presentation (section 7.4) and discussion of results obtained (section 7.5).

7.1 Therapy cycles

For the comprehension of the argument appears necessary to have an overview of the IRST oncological ward's operations. This has been briefly discussed in the section 5.4.5, but here has been developed in detail. Firstly, it is important to remember that the analysis done has not been based on medical expertise and it will not show the question on that side. So, the description of the operations will be done just from a logistical point of view since it is the relevant one in this work.

The oncological ward has the goal to cure the cancer, logically, and it works over cycles: when the doctor has detected the cancer and defined the therapy to administer to the patient, the rounds of treatments are scheduled in terms of repetitions number and intervals in the middle. This time required to pass between 2 different rounds is caused by the effect of the therapy treatment on the body, that is (out of the distress and any other physical and psychological effect on the patient) a momentaneous reduction of specific blood values which makes the patient unable to receive another administration for a period of time. The duration of this interval is not clear and depends by many factors; so before any administration, it is planned to do a blood test on the days before the treatment to check the patient's condition and authorize the following round. This process is well described by the graph below where "n" is the hypothetical intervals scheduled to between therapy cycles and "k" is the number of days to wait between blood tests and administration.

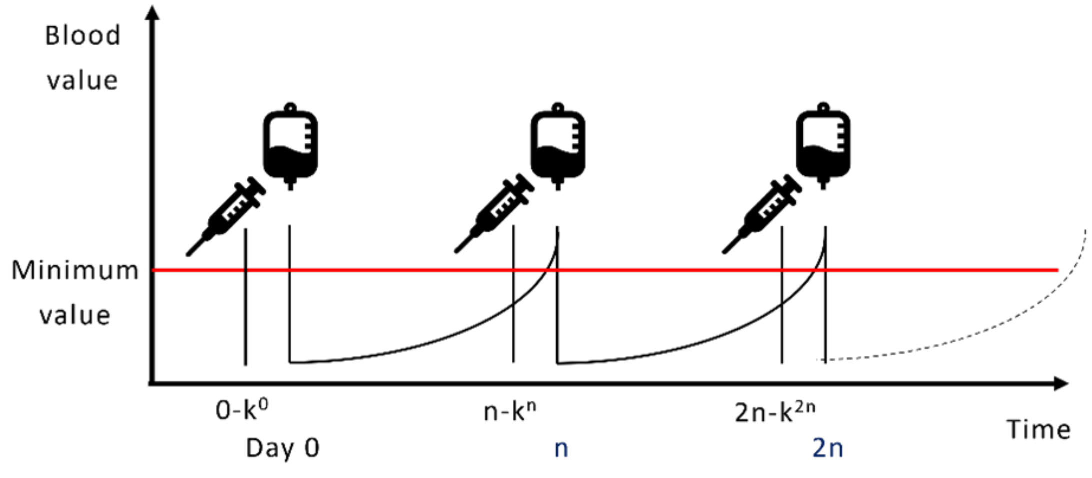

Figure 7.1: A graphical description of how therapy cycles work.

Bringing the focus on the "k": every time it is identified by the number of administration (with 'n' on the superscript) because it is not fixed, instead it depends on the logistical reasons of IRST. The oncological treatments work 5 days per week, and they work in different ways when planned on the last 4 working days (Tuesday, Wednesday, Thursday and Friday) where the day before the ward is open; compared to the first day of the week, where the blood test authorization must come from 3 days before (on the previous Friday). It may seem a limitation, but for the project goal (shown in the following sections) having data from 3 days before the blood test is precious information. So, up to now, the scheduling of the cycles and blood tests are done by setting 'k' equal to 1 (out of therapies on Monday) and following old schemas that provide a certain value of 'n' per each typology of therapy. But, as largely discussed, the elements of the production process of therapy are interrelated. It means that setting these values is impactful on other points of the flow. More precisely, the values of 'variables' create the following issues:

- 'n': using the current values means having the rate of negative blood tests about 20%. The old schemas used are not very precise, or better, at this moment it has become an issue for the volumes and for the impacts they have on the entire system.

- 'k': making the blood test a single day before therapy (and considering the possibility of making orders twice/week) implies ordering by predicting the number of positive outcomes from blood tests, to evaluate the related product needed to prepare the therapy. It is translated into a possibility of products being wasted and implies managing the workload on a single day, with the risk of overwhelming whenever extraordinary cases occur.

These aspects are manageable up to now, but they could not be anymore when the CCCRN project begins. Given that, the Healthcare Direction Unit is interested in exploring the possibilities of changing the approach by enhancing the scheduling process and the related activities. These are the reasons that brought to this analysis. In the following section, they have been translated into measurable objectives. Together there has been considered the sustainability dimensions affected by facing these issues.

7.2 Objectives for improving blood test scheduling

After a brief description of the organization and background, it is important to define the direction to take, or better, the questions to answer considering the problems depicted before. Concretely, building the algorithm to solve these means creating a system that can help to predict the patient response considering a set of data. Below are the 2 questions set to make that:

1. Giving a patient in a certain condition and a fixed period for blood tests and therapy: will he be ready to receive the therapy? Or, in other words, what will be the outcome of the blood test?

2. Since the increasing workload, IRST needs to spread it along more days: is it possible to identify a category of patients that can do the blood test 3 days before (instead of 1)? In the meanwhile, considering that each failed blood test means costs, is it possible to identify categories of patients that are better to schedule 1 day before therapy (instead of 3)?

This second point has been translated in a more practical perspective, by trying to predict the behaviour in 2 specific cases:

- patients with positive response to blood test 1 day before therapy (called "-1 Good") when they are moved to test blood values 3 days before.

- patients with a negative response to blood test 3 days before therapy (called "-3 Bad") when they are moved to test blood values 1 day before.

For this second task, the goal is reaching a significative reliability (in terms of accuracy) in distinguishing the cases for bringing all the possible cases to 3 days before. To make it, the data used in the algorithm for the 2 situations explained are the ones in the table table 7.1.

	-1	-3	Tot
Good	6957	1463	8420
Bad	844	288	1132
Tot	7801	1751	
Precision	89,18%	83,55%	88,15%

Table 7.1: Current numbers where '-1' are blood tests executed 1 day before and '-3' are blood tests executed 3 days before. While 'Good' and 'Bad' is the outcome obtained

Predicting the behaviour of patients for the 2 cases described means understanding the number of patients that will be good or bad on a certain day. But the real intention, due to organizational needs, is bringing all the possible cases to 3 days before and the other to 1 day, maintaining the highest value of accuracy possible.
The tabs table 7.2 and table 7.3 show the possible options considered in this analysis.

The variables used (in table 7.2 and table 7.3) are:
'X': -1 Good
'x1': portion of -1 Good still good in -3
'x2': portion of -1 Good bad in -3
'Y': -3 Good
'W': -1 Bad
'Z': -3 Bad
'z1': portion of -3 Bad good in -1
'z2': portion of -3 Bad still Bad in -1

	-1	-3
Good		Y - x1
Bad	W	Z - x2

Table 7.2: Table that describes what happens if all '-1 Good' are moved to '-3' for spreading the workload.

	-1	-3
Good	X - z1	Y
Bad	W - z2	

Table 7.3: Table that describes what happens if all '-3 Bad' are moved to '-1' for increasing the accuracy.

After the definition of those values, the 2 conditions could be joined and provide the final result of using these models for scheduling the blood tests.

Overall, the attention needs to be moved to reality and for evaluating the benefits of the results it is useful to analyse the practical implications of all cases, that is what can happen in reality when the response of the patients follows or not the schedule of the cycle and blood test. To present all the conditions, it can be used the "Confusion matrix" that organizes all the situations in 4 groups:

- True positive (TP): the patient is scheduled for a certain day and his values authorize the administration.
- True negative (TN): the patient is not scheduled for a certain day (because it was expected a low blood response) and, indeed, he appears not ready for the administration.
- False positive (FP): the patient is scheduled for a certain day, but his values do not authorize the administration.

- False negative (FN): the patient is not scheduled for a certain day (because it was expected a low blood response) and, instead, he is ready for the administration.

The goal is logically acting on the false cases. But what are the impacts of reducing "False positive" and "False negative" cases?
The FP cases regard the condition when the patient has come to receive the authorization to proceed with treatment, but it has been denied. It implies expenses that in the end appear useless, as the ones for the travel, most of the time are done by someone closely related to the car for the fragility of patients. On the other side there are useless expenses as well, for the materials and working time, with the missed possibility for other potentially ready patients (that has not been called since the available slots were full).
To evaluate the impact of these events it has been used the table x.y (tab measures for sust). These are some macro-dimensions and here they have been used to define and group the benefits caused by the introduction of this algorithm. Also here, this list can be a good proposal but not a definitive analysis. So, looking at the entire process it is possible to list the possible impacting factors:

- Facilities design. Travels are a known impacting factor on air condition, in particular the useless ones. In this case, it may concern the travel done by the patient and the one done by IRST for sending the blood test to be analysed in Pievesistina. This consequence impacts on environmental sustainability and it is placed in this category since IRST could consider extending their service including transportation (with all the limits needed for the implementation), by collecting all the necessities and designing a service that reduces the CO2 emissions. In this condition, this measure is strictly related to the green growth that is affected as well.

- Patient satisfaction. Going to the hospital for a blood test, or in general going out of home, can be a disease or a stress event. Also here, the condition worsens when it must be repeated in a few days. A wrong programme surely impacts on the social dimension of the patient, and surely it has many other facets not considered here.

- Waste reduction and management: making a blood test produces a certain amount of waste for the material used that, independently by its size, is a waste when it is unnecessary.
  In addition, anticipating the blood test would permit better management of the orders by avoiding the prediction of the success of blood tests and related products to build up the therapies.
  This is relevant because less prediction means less waste. In conclusion, the

enhancement in this sense has also consequences on better management of products in the warehouse, which could reduce the expired products.

- Savings in operational costs and enhanced profits: the time spent to execute a blood test can be translated into salary cost per hour/minute. It concerns the time of nurses who execute the test, the operators who move the test and transport it to Pievesistina, and it also concerns the missing opportunity to proceed with the administration of another patient.
  Similarly, better management of operations in warehouses would reduce the working time of operators and the number of extra-travels for urgent procurements, which are costs.
  Logically, still here the operational costs for useless activities are waste.

Instead, the FN cases regard all situations where a patient has not been scheduled but he has been ready to receive the treatment. Every situation like that impacts on:

- Patient satisfaction. Every missing patient ready for treatment could mean affecting the duration of medical care for him and eventually, also, the effectiveness of care itself. This condition can be related to 'Savings in operational costs and enhanced profits' and 'Research and Innovations' because the improvements of cure by telemedicine can be a good opportunity for reducing these numbers, so the missing consideration of this aspect may mean being lacking in this dimension.

- Affordability. Having a sustainable process for the workforce of IRST means being able to provide a universal cure. It is one of the core principles of the service of hospitals and it must be considered as a benefit of this approach.

Here is relevant to say that only for the first case has been possible to measure, because for the 'not scheduled patients' is impossible to know their condition, so the following improvements can be measured in the reduction of FP cases.

Being able to reduce these cases (with a certain reliability) concretely means impacting on the cases listed and answering the problems of the future situation. Given that, the point is to understand if it is possible to reduce all the aspects and work has been focused on the idea to directly avoid the occurrence of events by recognizing the 'false cases' and delay the scheduling.

7.3 Methodologies

The data used for the project have been extracted from operational databases of IRST from the start of 2022 to the end of June 2023. The data collection system in IRST is based on web applications that allow doctors, chemists and any operators of the hospital to operate. Before any operations, they have been managed using techniques that hide the real identity of the person in the exam: removal of identification attributes (as fiscal code), replacement of age with an age range and replacement of information about cancer location with a number (translatable only by IRST). The dataset consists of approximately 32 thousand rows (12 thousand after pre-processing), where each of them represents a therapy with some attributes about the patient and the time of the blood test required to make the therapy.

As anticipated, to face this classification problem it has been considered to use some ML algorithms. The reason for this choice is related to the high level of interpretability of the classifiers generated and the possibility of improving the analysis with the support of domain experts. The ones taken into consideration for this project are the following:

- Decision tree
- Support Vector Machines (SVM)
- Ensemble methods
- Random forest
- AdaBoost

The Decision tree has been considered for its ability to provide a clear description of classifiers, and key elements to involve domain experts in the development. SVM can be really helpful to find hidden relationships by handling non-linear data and it can be useful for its robustness to overfitting. Instead, the ensemble methods have been considered for their capacity to strongly improve performance by combining more classifiers. Random forest may provide very good results, in terms of stability of classifiers, in front of a stable training set. Then Adaboost is effective in detecting the cases “difficult” to classify, and this dataset could be full of them considering the short availability of attributes related to patients. Each of the classifier is set with the parameters that fits as most with the data (e.g. the minimum number of elements to create a leaf in Random forest trees).

Moreover, to reach the objective of moving as most patients as possible to 3 days before, it has been built new specific classifiers. The basic idea to verify the reaction of patients in certain conditions (in this case means testing the blood values 1 day or 3 days before) is creating a specialized classifier able to correctly distinguish those cases, then use it on the data of the opposite one. It means training the model by using only data regarding one 'case' and using it with the data of the other.

For this approach there have been used Decision trees for their interpretability and, to apply the method, the rows to classify were modified by changing the

	Precision	Recall	Support
0	0.88	0.42	725
1	0.87	0.99	2889

Table 7.4: AdaBoost performance on test-set.

TN	302
FN	40
TP	2849
FP	423

Table 7.5: Results of confusion matrix.

attribute "Dist_expected" to "-1" to "-3" and vice versa.

The expected outcomes of this work are 3 classifiers with related precision measures: one to support the scheduling of new cases (objective 1) and two for predicting the potential evolution of moving patients between the 2 cases, so "-1 Good" to -3 and "-3 bad" to -1.

7.4 Presentation of results

The work exposed started from a dataset of more than 32000 rows, and applying the pre-processing methods reduced the amount to about 12000. These data were split into train-set (70%) and test-set (30%) and then used to train the classifiers and test their efficacy to distinguish the rows between positive and negative. At this point, the results of the algorithm are evaluated by observing precision, recall and confusion matrix, to comprehend better the meaning of the results obtained and understand the effect of the correct or wrong predictions.

First, it has described the classifier for predicting new cases.
Considering the data used, IRST planning produces 20% of failed blood tests, which is translated in terms of the Confusion matrix in the percentage of "False positive cases". On the other side, as anticipated, the data about "False negative cases" are not present. So, to evaluate the accuracy it is used to set the accuracy equal to or lower than 80%.
The accuracy reached with the algorithms is up to 87,2%, but for understanding concretely what it would mean to implement this ML algorithm in scheduling operations of blood tests, it is important to look at the other measures (table 7.4 and table 7.5).

The picture described the outcome of the algorithm with the highest accuracy. From these data it is possible to get one important insight: this algorithm struggles in detecting negative cases, and below it is explained why.

The first clue comes from the number of "Predicted cases": the quantity of negative cases classified is only 9,5% of the total add a reference of the picture, which is way less than the percentage of negative cases over all the data (20%). But, this information alone would not have much meaning.
In fact, the big evidence for the inability to detect negative cases depends on the quantity of "False-positive cases" and, consequently, the value of "recall" for the class "0". Having this value equal to 0.42 means that over all the real negative cases, it has been possible to recognize as truly negative only 42% and all the others are FP, and they impact as described in the section 7.2. In the hypothetical condition of this testing phase these impacts should be multiplied for 423; and considering that is 11,7% of the total, the effect would be huge on the operational numbers of IRST (especially the ones of CCCRN).

Detecting the reasons for this behaviour it emerges another point to confirm the insight. Comparing the data distribution about "False positive cases", the percentage of data for each category of each attribute, with the distribution of "True positive cases": they are superimposable. The percentages differ shortly, that translated means that they are almost equal.
It reinforces the assumption of inability because the outcome here is that the algorithm has not been able to find differences between TP and FP, and it is the most evident demonstration.

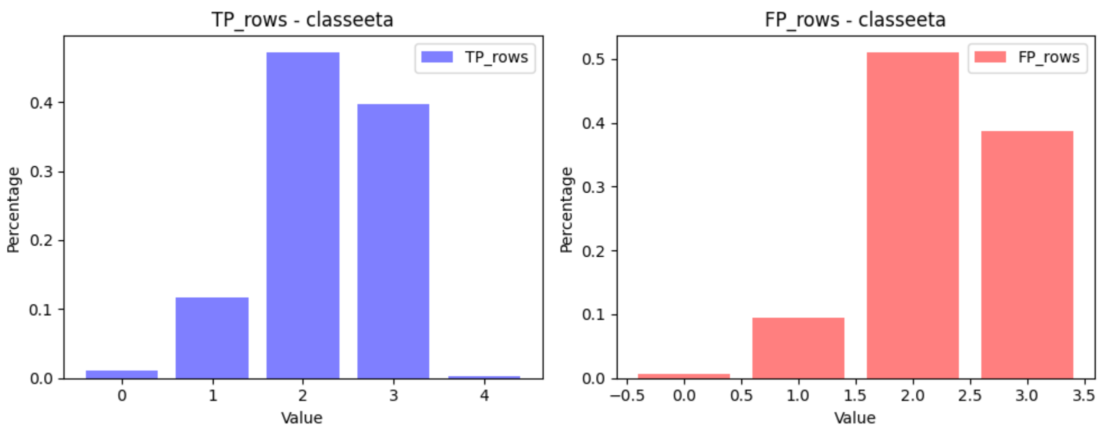

Figure 7.2: A graphical comparison of TP and FP cases about the age range parameter.

The issue presented above is reflected also in the development of Decision trees about the patients who made the blood test 1 or 3 days before the therapy, where the results are the ones in table 7.6.

These results are not encouraging since almost equal to the ones in the initial condition (table 7.1), even a bit less. Then, these decision trees for -1 day and -3

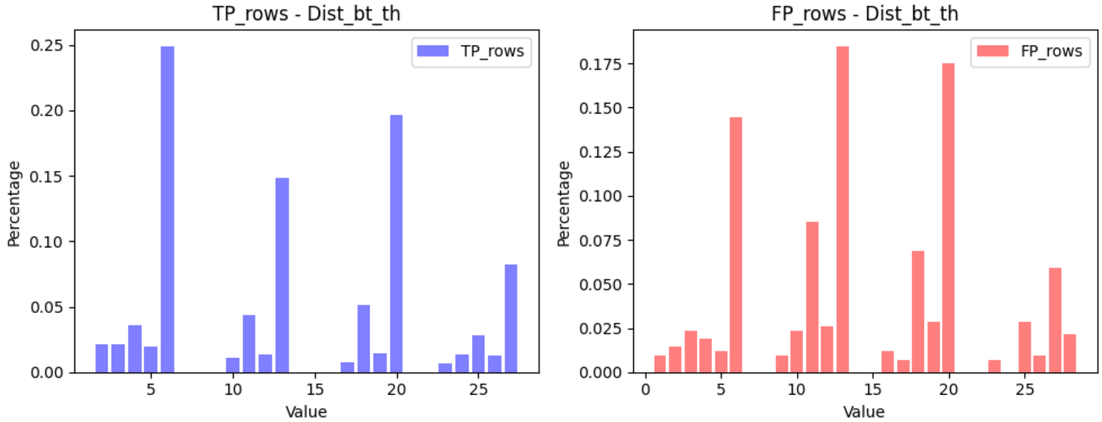

Figure 7.3: A graphical comparison of TP and FP cases about the parameter that measures the distance between the blood test and the previous therapy.

	Precision	Support
Decision tree 1 day	88,64%	7081
Decision tree 3 days	83,65%	1751

Table 7.6: Results of algorithms for moving patients between 1 and 3 days before treatment.

days have been able to classify as negative cases only 2,4% and 2,1% of the total, recalling as the problem of before.

Having trustworthy values would mean being able to understand (with a certain precision) which can be the effects of moving patients from one condition to another and comparing the quantities of "-1 Good", "-1 Bad", "-3 Good", and "-3 Bad" with their weight in terms of real impacting factors. But this is not the case, the accuracy is not enough and the models have not been able to provide any improvement.
The choice of using Decision trees may seem not worthy since the other algorithms provided better results, but there was a precise reason for that: they would permit also the description of the 'categories' of patients (by the value of attributes) that can be moved and which cannot. This planning operation of the patients would be data-driven, which is one of the opportunities provided by Digital Twin.

Also here, the method discussed would be extremely useful only if the classifiers would not be affected by the problem in classifying negative cases, as it is right now. From the data described above we can easily infer that the quantities are clearly low, even if in this case is not possible to make the analysis done before with the confusion matrix, and, considering the reasonings done for the classifier used to support scheduling of all patients, also these classifiers are considered as unreliable up to now.

The results would continue with an analysis of the hypothetical situation where the patients are moved in the directions described in the sub-chapter x.y about objectives by assessing the effectiveness of these choices and comparing the numbers, still with a certain level of reliability. It is not the case up to now, but in the following paragraph, it is described which can be the evolutions.

7.5 Conclusions

The presentation of outcomes offers a very good perspective on the objective of this example, by analysing why the results are insufficient. They showed the unreliability of the algorithm as a consequence of the data provided, demonstrated by overlapping the TP and FP cases and noticing that the differences were small. Recalling the concept explained in (CC scheduling BT), the data has been demonstrated as insufficient for extracting the critical information of this situation, which is a trustworthy prediction about blood test outcome. The focus of the conclusions is understanding why it happened.

The cause depicted as crucial for the unsuccess is the missing design phase. The data used were the ones about blood tests stored by IRST for other reasons and there has not been any meeting or discussion with doctors to outline the essential features to consider for extracting the valuable information. For instance, which data about patients are relevant for predicting their response in front of therapy treatments?

Several times in this thesis the focus has been placed on the detection of relationships between factors and events since they represent the opportunity to extract the critical information. Here, these have not been outlined before proceeding with the development, since this example was birthed without this phase. Therefore, it is possible to conclude that its unreliability demonstrated the relevance of these relationships and all connected impacts.

At the same time, the analysis done for the development of the Machine Learning algorithm and the structure built are precious for further developments since they focused on the significant knowledge to extract in this specific case. This long work has not been a simple demonstration of the necessity of the analysis phase, instead, it is a valid structure to use and simply adapt when the data to provide has been accurately designed.

Summing up, the missing data are a clear demonstration of the importance of the design phase. Adopting a Digital Twin based approach would permit to build properly the data structure able to represent the essential features of the assets (in this case, Patient), which is translated into a valid opportunity for extracting the knowledge of this critical process.

Chapter 8

Conclusions

This is the final chapter of the thesis, which sets out to retrace the course taken by relating the various topics covered to the objectives originally set. Therefore, at the conclusion of the work presented, this will be analysed according to the key steps that enabled the demonstration of the Digital Twins approach with regard to the therapy production process.

Overall evaluation of the work In the first part of the thesis, the focus was on the complexity of the concept of sustainability and sustainable development, with a particular focus on the health sector where this was particularly relevant on all 3 levels of sustainability. Here it emerged that sustainable development is identified by a characteristic: the profound interconnection between all dimensions. That is, when an event has an impact on a certain dimension of sustainability, this also has consequences on the other levels. This interconnection introduces a certain level of complexity into sustainable development, particularly when multiple aspects are considered.

In the following, the definition of such aspects to be considered in the sustainability assessment in healthcare was discussed, looking at a recently made proposal that can support IRST's sustainable transition. From here, the concept of digitisation was introduced as an opportunity to address and manage situations with multiple factors to be considered, as it allows managing high complexity and extracting value from this. This last point also revealed itself to be introductory to the concept of the Digital Twin, considering its origin, components and functionalities provided. From which the real value delivered by a Digital Twins approach was then discussed, and above all, one of the concepts on which the internship work was based was presented: the Web of Digital Twins.

Across the presented sections, the focus was on relationships and the ability to represent and exploit them, as these represent fundamental opportunities to extract critical information. This concept turned out to be potentially worthwhile in the complexities of those working in the healthcare field, and thus in IRST's activities. In particular, it was presented in the detailed analysis of the therapy production process and the points of intervention observed. Starting from the meetings with domain experts, it was possible to provide an overall description of the process, from which critical information could be extracted to address the situations that emerged. This work was used for the development of a Digital Twins-based solution proposal, which was presented immediately afterwards in all its components and together with the demonstration of how this proposal can address the critical processes discussed above. In support of the proposed analysis, a demonstration of the development of a data-driven model in the absence of Digital Twins support was provided, and this brought out the lack of information that could be extracted from the data provided, and thus the need for a structuring of the data based on the needs to satisfy.

This last point concludes the demonstration provided by this thesis of the value of the needs analysis phase and the Digital Twins approach with the support of domain experts.

Further developments A final comment should be made on the deliverables delivered to IRST. The model provided is the result of work carried out in collaboration with the co-supervisor of this thesis, who is a valid expert in the domain to address some of the critical issues that have emerged, but who does not know in detail other issues that have emerged as she does not work in the Pharmacy. Therefore, this proposal envisages a further review together with the Coordinator of Pharmacy technicians, the Oncological laboratory manager and the Pharmacy operators. The aim here would be to add all the necessary properties to represent real objects in a virtual environment, with the ultimate aim of extracting the necessary knowledge to deal with critical processes.

Net of these additional required activities, the deliverables for IRST can be considered absolutely valid for the development of the other critical processes. On the one hand, the algorithm for the prediction of blood test outcomes represents a framework for providing new data and the basic structure for carrying out new analyses, creating new models or simply adapting new ones. On the other hand, the description of the critical issues that emerged is in fact the outcome of a structured analysis of real problems. Each of these represents a valid starting point for more detailed studies with domain experts on these issues, proceeding with the extension or modification of the proposed DTs model. In the latter case, the potential is particularly great as it allows the possibility of starting specific projects (e.g. internships) aimed at the more detailed exploration of the processes in question, but having a basis for the analysis of the context certainly represents an important opportunity as it excludes all the 'problem exploration' work, thus allowing all the time available to be invested in the development of a contribution to IRST.

In addition, to support further developments, below are recalled some key concepts and presented some suggestions to consider for empowering the analysis, the model and the algorithm delivered:

- Focusing on relationships. Every event is a consequence of another one and the holistic view of them is the key for handling high-complex processes such as the one of therapy production.
- Involvement of domain experts. They are the sources of knowledge and proceeding without would mean working blindly. They can be engaged in all the relevant stages where they could provide this valuable contribution.
- Define a priori the dimensions of interest. Having the dimensions to consider from the initial stages is extremely valuable for evaluating the investment in terms of time and project to develop. As here, where the sustainability perspective has been used for determining the impacts, there may be many others.
- Always consider the mindset of future users. Having a well-designed system is useless if the users do not use it properly. Taking into consideration their mindset is extremely important for evaluating if developing a project could be a good idea or not.
- Consider an approach to problems inspired by Design Thinking. It is an iterative methodology to design focused on solving problems by understanding the users and keeping in contact with them to build the proper solution. It can be a good path to follow for exploring additional issues.

In closing, it can be argued that the Digital Twin approach is a potential possibility for IRST in addressing the challenges they face in the coming period, by improving the decision-making processes with data, as well as in supporting the sustainable development they seek. This concludes the thesis and the internship project, which will hopefully support IRST's transition and bring future benefits from a sustainable development perspective.

Bibliography

[1] Report of the world commission on environment and development : note /. page 374 p. :, Aug 1987. Includes bibliographical references.

[2] https://www.agenas.gov.it/comunicazione/primo-piano/2220-focus-regionali-sui-costi-energetici-dettaglio-di-tutte\-le-aziende-sanitarie-pubbliche, 2023. Focus on energetic costs of national healthcare system.

[3] Shama Ahmad. Environmental impacts of the u.s. health care system and effects on public health. *PLoS ONE*, 2016. PMID: 24097072.

[4] Ellen Balka, Karen Messing, and Pat Armstrong. Indicators for all: including occupational health in indicators for a sustainable healthcare system. *Policy and Practice in Health and Safety*, 4:45–61, 06 2006.

[5] Elio Borgonovi, Paola Adinolfi, Rocco Palumbo, and Gabriella Piscopo. Framing the shades of sustainability in health care: Pitfalls and perspectives from western eu countries. *Sustainability*, 10(12), 2018.

[6] https://www.slideshare.net/sucesuminas/business-analytics-from\-basics-to-value, 2014. Presentaiton of basic knowledge anput business analytics.

[7] María Carmen Carnero. Assessment of environmental sustainability in health care organizations. *Sustainability*, 7(7):8270–8291, 2015.

[8] Angela Y. Chang, Krycia Cowling, Angela E. Micah, Abigail Chapin, Catherine S. Chen, Gloria Ikilezi, Nafis Sadat, Golsum Tsakalos, Junjie Wu, Theodore Younker, Yingxi Zhao, Bianca S. Zlavog, Cristiana Abbafati, Anwar E Ahmed, Khurshid Alam, Vahid Alipour, Syed Mohamed Aljunid, Mohammed J. Almalki, Nelson Alvis-Guzman, Walid Ammar, Catalina Liliana Andrei, Mina Anjomshoa, Carl Abelardo T. Antonio, Jalal Arabloo, Olatunde Aremu, Marcel Ausloos, Leticia Avila-Burgos,

Ashish Awasthi, Martin Amogre Ayanore, Samad Azari, Natasha Azzopardi-Muscat, Mojtaba Bagherzadeh, Till Winfried Bärnighausen, Bernhard T Baune, Mohsen Bayati, Yared Belete Belay, Yihalem Abebe Belay, Habte Belete, Dessalegn Ajema Berbada, Adam E. Berman, Mircea Beuran, Ali Bijani, Reinhard Busse, Lucero Cahuana-Hurtado, Luis Alberto Cámera, Ferrán Catalá-López, Bal Govind Chauhan, Maria-Magdalena Constantin, Christopher Stephen Crowe, Alexandra Cucu, Koustuv Dalal, Jan-Walter De Neve, Selina Deiparine, Feleke Mekonnen Demeke, Huyen Phuc Do, Manisha Dubey, Maha El Tantawi, Sharareh Eskandarieh, Reza Esmaeili, Mahdi Fakhar, Ali Akbar Fazaeli, Florian Fischer, Nataliya A. Foigt, Takeshi Fukumoto, Nancy Fullman, Adriana Galan, Amiran Gamkrelidze, Kebede Embaye Gezae, Alireza Ghajar, Ahmad Ghashghaee, Ketevan Goginashvili, Annie Haakenstad, Hassan Haghparast Bidgoli, Samer Hamidi, Hilda L. Harb, Edris Hasanpoor, Hamid Yimam Hassen, Simon I. Hay, Delia Hendrie, Andualem Henok, Ileana Heredia-Pi, Claudiu Herteliu, Chi Linh Hoang, Michael K. Hole, Enayatollah Homaie Rad, Naznin Hossain, Mehdi Hosseinzadeh, Sorin Hostiuc, Olayinka Stephen Ilesanmi, Seyed Sina Naghibi Irvani, Mihajlo Jakovljevic, Amir Jalali, Spencer L. James, Jost B. Jonas, Mikk Jürisson, Rajendra Kadel, Behzad Karami Matin, Amir Kasaeian, Habtamu Kebebe Kasaye, Mesfin Wudu Kassaw, Ali Kazemi Karyani, Roghayeh Khabiri, Junaid Khan, Md Nuruzzaman Khan, Young-Ho Khang, Adnan Kisa, Katarzyna Kissimova-Skarbek, Stefan Kohler, Ai Koyanagi, Kristopher J. Krohn, Ricky Leung, Lee-Ling Lim, Stefan Lorkowski, Azeem Majeed, Reza Malekzadeh, Morteza Mansourian, Lorenzo Giovanni Mantovani, Benjamin Ballard Massenburg, Martin McKee, Varshil Mehta, Atte Meretoja, Tuomo J Meretoja, Neda Milevska Kostova, Ted R Miller, Erkin M Mirrakhimov, Bahram Mohajer, Aso Mohammad Darwesh, Shafiu Mohammed, Farnam Mohebi, Ali H Mokdad, Shane Douglas Morrison, Seyyed Meysam Mousavi, Saravanan Muthupandian, Ahamarshan Jayaraman Nagarajan, Vinay Nangia, Ionut Negoi, Cuong Tat Nguyen, Huong Lan Thi Nguyen, Son Hoang Nguyen, Shirin Nosratnejad, Olanrewaju Oladimeji, Stefano Olgiati, Jacob Olusegun Olusanya, Obinna E Onwujekwe, Stanislav S Otstavnov, Adrian Pana, David M. Pereira, Bakhtiar Piroozi, Sergio I Prada, Mostafa Qorbani, Mohammad Rabiee, Navid Rabiee, Alireza Rafiei, Fakher Rahim, Vafa Rahimi-Movaghar, Usha Ram, Chhabi Lal Ranabhat, Anna Ranta, David Laith Rawaf, Salman Rawaf, Satar Rezaei, Elias Merdassa Roro, Ali Rostami, Salvatore Rubino, Mohamadreza Salahshoor, Abdallah M. Samy, Juan Sanabria, João Vasco Santos, Milena M Santric Milicevic, Bruno Piassi Sao Jose, Miloje Savic, Falk Schwendicke, Sadaf G. Sepanlou, Masood Sepehrimanesh, Aziz Sheikh, Mark G Shrime, Solomon Sisay, Shahin Soltani, Moslem Soofi, Moslem Soofi, Vinay Srinivasan, Rafael Tabarés-Seisdedos, Anna Torre, Marcos Roberto Tovani-Palone, Bach Xuan Tran, Khanh Bao Tran, Eduardo A. Undurraga, Pascual R Valdez, Job F M van Boven, Veronica Vargas, Yousef Veisani, Francesco S Violante, Sergey Konstantinovitch Vladimirov, Vasily Vlassov, Sebastian Vollmer, Giang Thu Vu, Charles D A Wolfe, Naohiro Yonemoto, Mustafa Z. Younis, Mahmoud Yousefifard, Sojib Bin Zaman, Alireza Zangeneh, Elias Asfaw Zegeye, Arash Ziapour, Adrienne Chew, Christopher J L Murray, and Joseph L Dieleman. Past, present, and future of global health financing: a review of development assistance, government, out-of-pocket, and other private spending on health for 195 countries, 1995–2050. *The Lancet*, 393(10187):2233–2260, 2019.

[9] Andrea Chiarini, Alex Opoku, and Emidia Vagnoni. Public healthcare practices and criteria for a sustainable procurement: A comparative study between uk and italy. *Journal of Cleaner Production*, 162:391–399, 2017.

[10] Health Care Climate Council. `https://climatecouncil.noharm.org/`, 2020. This playbook captures how hospitals are operationalizing climate solutions – inspiring and encouraging hospitals to engage further in climate action while providing a path forward to achieving measurable progress and outcomes. The time has never been more critical for hospitals and health care to take action.

[11] R G Evans and G L Stoddart. Producing health, consuming health care. *Soc Sci Med*, 31(12):1347–1363, 1990.

[12] World Health Organization. Regional Office for Europe. Environmentally sustainable health systems: a strategic document. 2017. WHO/EURO:2017-2241-41996-57723.

[13] Edward H. Glaessgen and D. S. Stargel. The digital twin paradigm for future nasa and u.s. air force vehicles. 2013.

[14] Michael Grieves and John Vickers. *Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems*, pages 85–113. Springer International Publishing, Cham, 2017.

[15] Martin Hensher. Incorporating environmental impacts into the economic evaluation of health care systems: Perspectives from ecological economics. *Resources, Conservation and Recycling*, 154:104623, 2020.

[16] `https://www.innerdevelopmentgoals.org/`. Home page of the project.

[17] Dennis L Kodner and Cor Spreeuwenberg. Integrated care: meaning, logic, applications, and implications–a discussion paper. *Int J Integr Care*, 2:e12, 2002.

[18] Elizabeth Koff and Nigel Lyons. Implementing value-based health care at scale: the NSW experience. *Med. J. Aust.*, 212(3):104–106.e1, February 2020.

[19] B G Link and J Phelan. Social conditions as fundamental causes of disease. *J Health Soc Behav*, Spec No:80–94, 1995.

[20] Mengnan Liu, Shuiliang Fang, Huiyue Dong, and Cunzhi Xu. Review of digital twin about concepts, technologies, and industrial applications. *Journal of Manufacturing Systems*, 58:346–361, 2021. Digital Twin towards Smart Manufacturing and Industry 4.0.

[21] Robert F. Lusch and Satish Nambisan. A service-dominant logic perspective. *MIS Quarterly*, (1):155–176, 2015.

[22] Rama Mehra and Milind Kumar Sharma. Measures of sustainability in healthcare. *Sustainability Analytics and Modeling*, 1:100001, 2021.

[23] James Messelbeck and Michael Whaley. Greening the health care supply chain: Triggers of change, models for success. *Corporate Environmental Strategy*, 6(1):39–45, 1999.

[24] Shyam Varan Nath and Pieter van Schalkwyk. *Building Industrial Digital Twins*. Packt, 2021.

[25] United nations. Transforming our world: the 2030 agenda for sustainable development. 2015.

[26] David Pencheon. Developing a sustainable health and care system: lessons for research and policy. *Journal of Health Services Research & Policy*, 18(4):193–194, 2013. PMID: 24097072.

[27] Michael E. Porter. `https://www.hbs.edu/ris/Publication%20Files/20060502%20NACDS%20-%20Final%2005012006%20for%20On%20Point_db5ede1d-3d06-41f0-85e3-c11658534a63.pdf`, 2006. Annual Meeting of National Association of Chain Drug Stores.

[28] Ben Purvis, Yong Mao, and Darren Robinson. Three pillars of sustainability: in search of conceptual origins. *Sustainability Science*, 14(3):681–695, May 2019.

[29] Tarunpreet Kaur Rattan, Mahesh Joshi, Gillian Vesty, and Sharad Sharma. Sustainability indicators in public healthcare: A factor analysis approach. *Journal of Cleaner Production*, 370:133253, 2022.

[30] Alessandro Ricci, Angelo Croatti, Stefano Mariani, Sara Montagna, and Marco Picone. Web of digital twins. 22(4), 2022.

[31] Alessandro Ricci, Angelo Croatti, and Sara Montagna. Pervasive and connected digital twins—a vision for digital health. *IEEE Internet Computing*, 26(5):26–32, 2022.

[32] Tilmanorcid Santarius and Josephin Wagner. Digitalization and sustainability: A systematic literature analysis of ict for sustainability research. *GAIA - Ecological Perspectives for Science and Society*, 32:21–32, 2023.

[33] David Santillo. Reclaiming the definition of sustainability (7 pp). *Environmental Science and Pollution Research - International*, 14(1):60–66, Jan 2007.

[34] Roberto Saracco. Digital twins: Bridging physical space and cyberspace. *Computer*, 52(12):58–64, 2019.

[35] Peter Seele and Irina Lock. The game-changing potential of digitalization for sustainability: possibilities, perils, and pathways. *Sustainability Science*, 12(2):183–185, March 2017.

[36] Prince Kwame Senyo, Kecheng Liu, and John Effah. Digital business ecosystem: Literature review and a framework for future research. *International Journal of Information Management*, 47:52–64, 2019.

[37] `https://www.irst.emr.it/it/irst-informa/notizie/tutte-le-notizie/trasparenza-relazione-rendicontazione-bilancio\-sociale-irst-2021`, 2022.

[38] `https://sustain2030.de/en/`. Home page of this project about SDGs and their interrlations.

[39] `https://www.digitaltwinconsortium.org/initiatives/the-definition-of-a-digital-twin/`, 2020. Definition of DIgital twin by Digital Twin Consortium.