BACHELOR'S THESIS / BIOMEDICAL ENGINEERING 2020

THE RISE OF SMART HOSPITALS: Design and implementation of a decision-making support tool for the SMART ICU of the Vall d'Hebron University Hospital

Pau Garcia i Morales

Universitat Pompeu Fabra Barcelona

Bachelor thesis on Biomedical Engineering

Universitat Pompeu Fabra

THE RISE OF SMART HOSPITALS: *Design and implementation of a decision-making support tool for the Smart ICU of the Vall d'Hebron University Hospital.*

Pau Garcia i Morales

Supervisor: Dra Yolima Cossio Gil and Zaira Benítez Díaz

Co-supervisor: Prof. Miguel A. González Ballester, DPhil (Oxon.)
Vall d'Hebron University Hospital | Department of Information and Communication Technologies

July 2020

Universitat Pompeu Fabra Barcelona

Dedicatory

To my parents, for always loving and supporting me. There was not parenting book in the world that could prepared you for me and my almost pathological curiosity. I appreciate how you raise me and all the things you did for me, there is no way I can pay you back.

Acknowledgments

I take this opportunity to express my gratitude to Vall d'Hebron University Hospital for allowing me to take part in the project on this text and providing me with the facilities being required. With special mention to Yolima Cossio, who believed that a junior biomedical engineer with a greater interest in management could provide positive value to a team of experienced healthcare professionals. I would like to express also my warm thanks to all the people who led me to her, thanks to Susana Domingo, Esther Riambau and Laia Arnal for being a great professional example to follow.

I would also like to thank my project external guide, Miguel Ángel González, from Universitat Pompeu Fabra who always answered my questions quickly and efficiently. His good advisements and suggestions have helped me along with the realization of this project.

For their support and guidance in the project, I am thankful to Ana Cía for her friendly advice and constructive criticism while programming and to Zaira Benitez, who shared a truthful and always careful view on several issues related to this text. I would also thank them for their availability to resolve all my doubts and situations of uncertainty. Hence, I am also grateful to some the members of the IT department of the hospital that help me during those months. Next, I wish to express my thanks to all the members of the Evaluation and Clinical Decision Support Unit of the Vall d'Hebron University Hospital for receiving me the way they did, thanks Lali, Marta, Alba and the rest of the team. It was a pleasure sharing the office with all of you.

I finish this section by placing on record that I am extremely thankful with the team of intensivists who taught me how critical care medicine works, for sincere and valuable guidance about the project and clinical management in general. To Ricard Ferrer, Jesús Martínez, Marcos Pérez and Manel Santafé from Vall d'Hebron University Hospital and to Francisco Parrilla from Hospital del Mar, thanks for being the kind of physician every engineer dreams of.

Abstract

As new decade begins, healthcare system will continue to face challenges of the past as well as new issues that emerge: prolonged life expectancy along with the increasing complexity of chronic treatment, changing patient expectations partially motivated for a generational conflict or occupational burnout among healthcare providers added to a predicted shortfall of medical staff in the next ten years. All while, healthcare expenditures are spiraling out of control. Moreover, the outbreak of COVID-19 and the current threat of resurgence has stressed this already overloaded scenario in which the intensive care unit (ICU) stands as a key player in the multisectoral response of the influenza pandemic plan.

This text is focused on the design, development and delivery of trustworthy software that can support real improvements in critical care outcomes. The clinical management decision-making support tool presented here wants to be a driver for improvements in operating costs and increase the productivity and efficiency of ICU.

From planning to execution, the project must be understood under the scope of Agile IT following a spiral development model. Speed of execution became a major source of advantage fueling iterations to achieve first a mockup, then a minimal viable product and finally a functional product. Therefore, an evaluation and risk analysis criterion were laid out to perform an execution roadmap and a mitigation risk strategy. Finally, I attempted to review the tool presented as an integral part of a vision containing IT developments, optimization of processes and cultural change as a further approach to the smart hospital.

Keywords

Keywords: Internet of Medical Things, Smart Hospital, Business Intelligence, Digitization of Healthcare, Intensive Care Unit, Clinical Management, Agile IT, Spiral Development Method, ETL, MicroStrategy.

Index

1. INTRODUCTION

The world of healthcare is facing many challenges, including a fundamental technology-based change in the way care is delivered and value is proposed [1]. The sector needs to take advantage of being in the cusp of the fourth industrial revolution and work to create more effective systems that help health providers to deliver better care at lower cost [2], [3]. But the challenge that lies behind this morphing is the extraordinary complexity of healthcare delivery. Medical understanding, diagnostic tools and treatment options are evolving faster than ever, so knowledge, resources and processes must be continually updated [4].

In outdated fast-paced critical care units, clinicians could make multivariate high-risk decisions based on incomplete information [5]. Therefore, there was no efficient and cost-effective way to generate a holistic view of the patient, far from it there was a way to evaluate clinical management decisions and operational data. In this old scenario, the problem was disseminated data and disconnected systems that could prevent ICU from achieving their desired clinical outcomes. This same disconnected systems, poor data quality and the difficulty of changing providers behaviours made healthcare organizations a traditionally risk-averse sector in adopting innovation and to derive insights from data and analytics [6].

In the last decade, the fast development of electronic medical records, interoperability, connectivity with medical devices and streaming analytics brought advanced information with near real-time analysis and mitigated some of the issues described above [7]. In this new scenario, the ICU stands as a highly technological environment where each patient generates thousands of data-points per day. Seizing this, intensivists have used individual patient data to monitor and follow organ failure severity with widely used scoring systems [8]. Further, they have started aggregating information on physiology and patient characteristics to generate severity of illness and prognostic scores such as NAS [9] or APACHE [10].

Nowadays, technology is playing an integral role in healthcare worldwide and data analytics has become increasingly useful in operational management, but also in other disciplines such as epidemiology or oncology [11]. Some of the key milestones include the digitalization of health records, access to big data and advanced software applications. These presented various advantages in the healthcare sector including ease of workflow, faster access to information and lower health care costs [12].

Data in this new paradigm are abundant, yet most of the data collected are still wasted thus missing the opportunity of using it to understand patient profiles and improve the management of critical care unit. There are a plethora of data in the ICU generated by the Internet of Things (IoT) or, to be more precise Internet of Medical Things (IoMT) which is creating a vast amount of data faster and more detailed than ever before. Meanwhile, health care costs are spiralling out of control with a spending projected to rise in Spain by 9% per year up to 105.000 millions of euros in 2020 and continues to expand faster than economy [13] - [14].

1.1 Current Healthcare Situation: A matter of demographic divide

For the last decade, it has been outlined and agreed on that ageing of population implies a major challenge for healthcare systems [15]. As millennials, generation Z and baby boomers enter new life stages at the same time, there will be simultaneous demands for lower cost, convenient care delivery and better management of chronic illness [16]. The public healthcare system must evolve to meet the needs of these groups and others, both in terms of where they converge and where they deviate. It is likely that many individuals currently entering retirement will live longer than earlier generations. However, they will also live sicker, increasing eventually the need for complex care [17]. Many of them will suffer from one or more chronic conditions, including diabetes, heart disease, cancer, hypertension, high cholesterol, arthritis and anxiety among others that, in an illness situation might trigger to a critical care treatment plan.

This scenario has been stressed with the irruption of coronavirus disease 2019 (COVID-19) which is expected to have long-lasting impacts on the Spanish healthcare system. As the pandemic spread across the globe, ICUs have seen jeopardized its capability to treat acute patients. The challenges of worldwide ICUs facing the pandemic are streamlining of workflows for rapid diagnosis and isolation, clinical management, and infection prevention (that will matter not only to COVID-19 patients but also to healthcare workers and other patients who are at risk from nosocomial transmission) [18]. Hospital administrators, ICU practitioners, governments, and policymakers must prepare for a substantial increase occasionally critical care bed capacity, with a focus not only on infrastructure and supplies, but also on staff management.

It will be challenging, but imperative, to create a system that balances the needs for these very different demographics whilst the rise of pandemic threat. For that reason, health systems will also need a larger workforce, but although the global economy could create 40 million new health sectors jobs by 2030, there is still a projected shortfall of almost 10 million physicians, nurses and midwives globally over the same period according to World Health Organization (WHO) [19]. Indeed, the system not only needs to attract, train and retain more healthcare professionals but also needs to ensure their time is used where it adds more value. That is why the lookout for more efficient and effective management models of critical care units resources will be needed.

1.2 Vall d’Hebron Barcelona Hospital Campus

Vall d’Hebron Barcelona Hospital Campus is the combination of four institutions in all fields of health, from healthcare to teaching and research: Vall d’Hebron University Hospital (with its three specialist centres: General; Maternity; and Traumatology, Rehabilitation and Burns), the Vall d'Hebron Research Institute, the Vall d’Hebron Institute of Oncology, and the Multiple Sclerosis Centre of Catalonia. These institutions join forces to make themselves larger, more useful, more productive and even more effective and stand out for the quality of its actions.

Vall d'Hebron University Hospital (VHUH) is the largest hospital complex in Catalonia and one of the biggest hospitals in Spain with more than 1,100 beds, a team of 7,100 professionals and an annual budget of 579 million euros [20]. The hospital is a leader in the Catalan Public Health System and a key player in integrating healthcare and quality of life in its area of influence that covers a population over 430,000 inhabitants although in some pathologies is extendible to all the population of Catalonia over 7,000,000 inhabitants.

Being a leading healthcare centre is a matter of service, innovation and quality but also volume. The figures from Vall d’Hebron Barcelona Hospital Campus are outstanding in all aspects, from the number of annual visits to surgical procedures per year (i.e. Table1). More than 60 years of experience at the front line of clinical care, proof the status of the centre as a reference in Spain. Vall d’Hebron Hospital was inaugurated in 1955, and its history has been marked by some of the most relevant highlights in the story of Spanish medicine [21]. Up to modern times, when VHUH reformulated spaces to multiply ICU bed capacity[1], redesign protocols and prepare their professionals to cope with the COVID-19.

+614,000	Patients per year
+32,000	Surgical procedures per year
+907,000	Outpatient activity
+1,200,000	Patient view per year
+360	Adult transplants
+62,500	Discharges
+900	Active Clinical Trials
+80	Research Groups
+1,100	Publications in Scientific Journals per year.

Table 1 *Annual figures from Vall d'Hebron University Hospital in 2019.*

1.2.1 Management Model of the Vall d'Hebron Barcelona Hospital Campus

The principles of VHUH can be summed up in one: "To put the patient at the heart of everything". That covers the three main pillars of the hospital: knowledge, fluidity and agility in processes, and safety for patients and workers alike (i.e. Figure 1). The project in this text is built around these too:

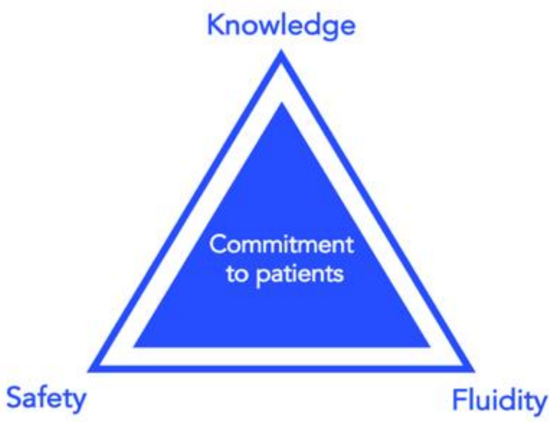


Figure 1 *Three main pillars of the management model of the Vall d'Hebron University Hospital.*

1 Pre-pandemic scenario: 82 adults' bed and 41 children and neonate's bed. || Pandemic Scenario: 196 adults' bed (181 for COVID-19's patients and 15 for no-COVID-19's patients) and 45 children and neonate's bed (4 for COVID-19's patients and 41 for no- COVID-19's patients).

Knowledge

Use the teaching capacity and research activity to improve services.

Fluidity

Being constantly working to improve clinical care processes, to become more efficient in the activity of the centres. Constantly improving and becoming more flexible to help the patients.

Safety

Guarantee medical safety for patients and professionals in all activities.

Under this model the hospital is developing programs that makes the campus a leading international centre. The project in this document reach amongst other objectives: (a) to humanize the settings by improving the care of acute patients through a business intelligence tool, (b) to be more sustainable by being commitment with waste in care in a broader sense, (c) to be more collaborative inside and outside the hospital by stablishing a collaboration between Vall d'Hebron University Hospital and Universitat Pompeu Fabra through an internship program.

1.2.2 ICU meeting the Internet of Things

The mission of ICU is to take care of all critical or potentially critical hospital patients using advanced monitoring and support systems. The unit's work with patient is carried out both within the ICU and outside of it, 24 hours per day, every day of the year. The unit is treating 2000 of the most complex patients every year. The refurbishment of the infrastructure cost 20 million euros in 2018 and allows the unit to reach the 3.500m2 with 56 individual boxes becoming the biggest ICU in the Spain and one of the most modern in Europe.

IoT solutions can be divided into four main layers: devices, networks, services and applications [22] [23]. In the Smart ICU all levels listed above are applied to achieve a holistic view of acute patients. Sensing devices and other medical devices connected to the patient inform about parameters like the pulse, breathing rate and blood pressure just to mention a few. This information is continuously updated and send to the concentrator of signals (i.e. *DigiBox*) that build the second layer. Additional important information is captured through the Centricity Critical Care (CCC) software interface provided by GE

Healthcare including for example the conscious level of the patient or nursing practices among others. Despite that sensing devices are essential to identify and collect key health parameters further exemplified in the methods section, the sensing layer and the network one and their technical intricates are beyond the scope of this text.

One of the most cutting-edge developments running at the unit is known as the *Smart Display*. This IoT tool is embodied in an 80 inches display that shows clinical information of the health status of each bed patient at the ICU. The smart display is located at the central control area and correlate the patient, the box where the patient is bedded and, its hemodynamic, neurological, renal and ventilatory states in a carrousel dynamic view. Information instantly refreshes and popup before fading away. Despite a proven utility and efficacy among a huge range of professionals in the critical care unit, one of the main needs overlooked by the project is the need for a clinical management tool. Around this unexploited need the project of this text is born and based on the experienced acquired in a very similar tool implemented in the neonatal unit.

This tool wants to be useful to identify the status of ICU, bottlenecks and possible wastes to achieve a better handled management of the unit. It will be embodied in the paperless or digitization strategy of the hospital. The same design strategy as the smart display is going to be applied to this tool, which can be easily described as a virtual tool emulating the cockpit display of pilots: information straightforward to the user, easy to access and identify, to achieve a more informed decision-making.

1.3 Objectives

Data-driven management applied to ICU will allow not only the management of unit resources and evaluation of the unit performance but has other conveniences including the implementation and monitoring of clinical protocols, the optimization of patient flows and a better planning and transition of care and discharge [24]. Then, in this case but also in general, the emergence of big data and data-driven strategies in healthcare presents both tremendous opportunities as well as unprecedented challenges. The objectives in this project can be divided in primary and secondary objectives:

(a) **Primary set of objectives: Information when, where and how it is needed.**

The main objective of this project is to build a decision-making support tool where data and information will be integrated back into existing workflows and delivered to the right person at the right time. Information when, where and how clinicians need it. Thus, this project is focused on data, information and workflow issues that have a direct impact on the quality and efficiency of care. The tool presented is oriented to the three main profiles identified during the definition stage and explained in detail further below (i.e. Section “2.1 Determining the objectives”).

The solution proposed is a clinical management information system that not only aggregate comprehensive data, but it helps to prioritize the most relevant insights to enable faster and more informed decision-making. Thereby, this technology has the potential to improve efficacy and efficiency in intensive care unit and identify evidence-based practices and management plans that at the end, will deliver better results with reduced risk.

(b) **Secondary set of objectives: Achieving an Agile operating model.**

The project will be buffered in an agile operating model that will become a rigor principle from planning to execution. For this reason, the secondary objective of the project is about deploying the solution following a certain methodology (i.e. Section “2 Methods – Spiral Development Model”) and achieving a good balance between both engineering gears and business management-oriented concepts. Speed of execution will become a major aspect of the project to fit the requirements due to the public health emergency linked to the outbreak of the COVID-19 pandemic.

Note that the decision-making support tool presented in this document is specially designed for Smart ICU of VHUH. This implies two mainly commitments: First, the creation of tailor-made functionalities for the patient profile in adult’s intensive care unit. Second, fully alignment to the data-driven strategy of the organization. Even such level of customization, it does not compromise future scalability of the project due to the methodology applied to the development. The idea behind this, is that this tool can be easily realigned to other critical care units of the hospital or even exported to any of the others seven high complexity hospitals belonging to Institut Català de Salut (ICS) network, leveraging the initial effort by achieving even a stronger impact.

2. METHODS

The method section is structured following the four main steps of the Spiral Development Model (SDM) and contains business management-oriented engineering concepts in order to design, develop and deploy the solution proposed in the section above (i.e. section "1.3 Objectives").

Spiral Development Model

The SDM is a risk-driven software development process model based on a model relaying on iteration and influenced by some of the concepts of the waterfall model [25]. The SDM meet a formal definition of the project while following evolutive dynamics [26]. The project progresses through several stages, from the conceptualization of requirements following a development stage to the next phase of improvements to finally end up with the release (i.e. Figure 2) [27].

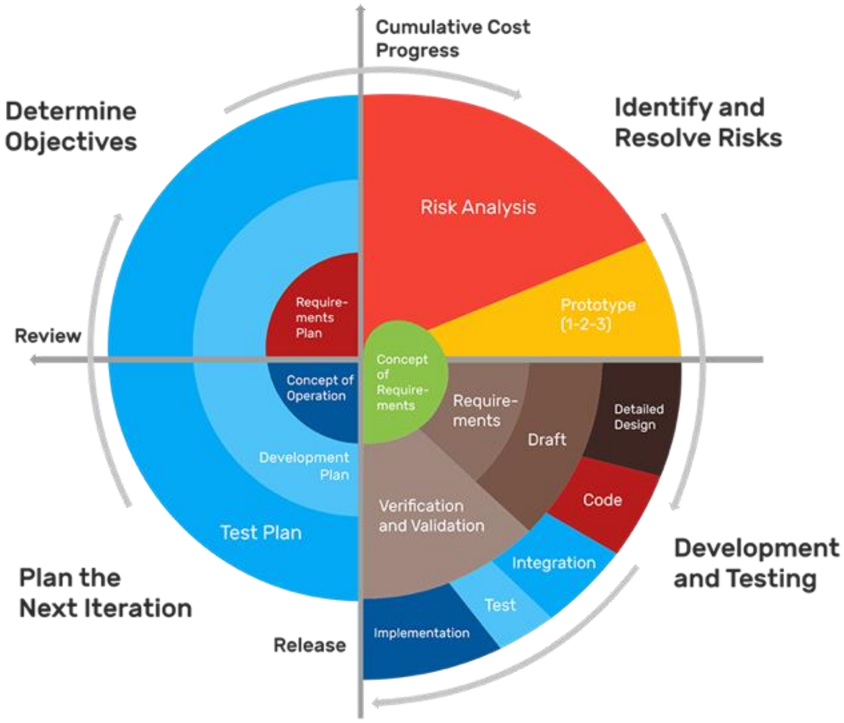


Figure 2 Diagram illustrating the main steps in the Spiral Development Model.

Like any other software development approximation, the Spiral Model has some scenarios where it is more effective [28]. Apparently, the blessings of the model are more evident when the project is relatively big, and a fast release of the software is needed. Both characteristics seem to fit in this project due to the scale and impact of the tool and, the haste to mitigate the risks of the pandemic scenario. Another important characteristic is that a mock-up of the software is needed, like in this case to validate needs with clinicians. This strategy also seems appropriate when the requirements of the projects are complex, or they are not clear enough. Therefore, to cope with the pace of such a complex environment as the ICU, it is relevant to mitigate the risk of change in user's needs. Finally, this methodology can be successfully implemented if the compromise between stakeholders is long-term compromised. Since all stakeholders belong to the VHUH and the project is prioritized in their internal backlog the commitment seems undertaken at least till the end of the first release. A detailed analysis of most popular managing models was conducted in advance, considering the waterfall model, the iterative and incremental family of models and Scrum among others (i.e. Figure 3). In the light of the above, the SDM look to fit the most the project. In the table below the graphical representation of the models considered.

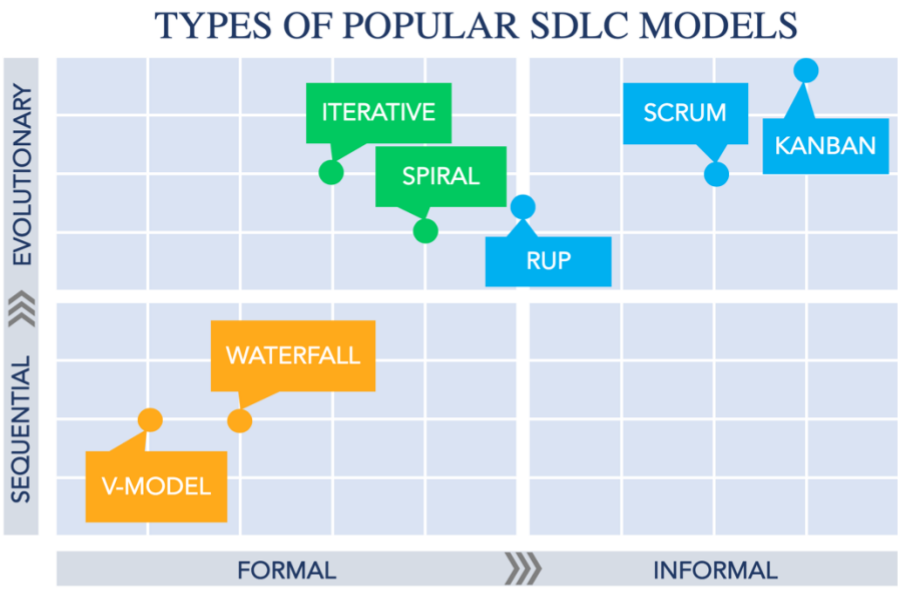


Figure 3 *Types of popular System Development Life Cycle (SDLC) models and the position of SDM.*

The main advantages of using this model against the other approximations initially considered are: (a) Added functionalities or changes in the way the software is conceived can be done in later stages or iterations such as new scores or indicators of the tool; (b) Cost estimation is easy because the construction of the prototype can be done in little releases. Here is important to qualify costs as opportunity and implementation costs, not in term of traditional financial costs of a project to be developed in a company; (c) Closely related to it, this way of repeated development can help with de-risking the project (see section 2.2 "Identify and Resolve the Risks" and section 2.4 "Evaluation, planning the next iteration").

Ultimately, the model is rooted on a development team that starts working with a set of requirements and moves to a development phase for that specific set (see section 2.1 “Determining the objectives”). Here is where the iterations are performed, each iteration adds a bigger spiral stage until the software is ready for production. As is explained above, the model is basically based on four stages and each project needs to customize those phases to optimize the results:

I. Determining the objectives
II. Identifying and resolving risks
III. Engineering Stage
IV. Evaluation

2.1 Determining the objectives

The seed stage of this phase was settled down on the 08th of January in a meeting with Dra. Yolima Cossio who is further introduced in this section. In the meeting, both agree in determining the objectives of the project and that for reaching those objectives, a plan should be scheduled. This first document included cost estimation, calendars and resources employed for achieving the iteration proposed by the end of the 2020’s academic course. Moreover, different requirements to conduct a fluent communication within the analyst (myself) and the clinicians were established. This also included the strategic creation of a team and the selection of an accurate working methodology. The three main front lines to cover to assure correct deployment of the technology proposed and in general, the digitization of the unit were (i.e. Figure 4):

a. Information Technology (IT) as the main driver for innovation. This covers the most challenging and complex tasks for the implementation a feasible solution: compelling software architecture, data analytics and visualization and the ability to deploy, configure, troubleshoot, secure manage and monitor IoMT solutions.
b. Cultural change improving digital disruption. Innovation is more than a technology problem. Leaders need to encourage people to think and act differently and set a culture of constant change. Is imperative to involve end-users in the

design process because new products must be embraced by employees from the begging, from all working ranges and all roles [29].

c. Optimization of the clinical process. The product in this text, must be understood as an element in a clinical process that runs inside a particular hospital circuit. This tool must be optimized to fit in the clinical pathways to achieve the desired objective: improve efficiency and efficacy of care.

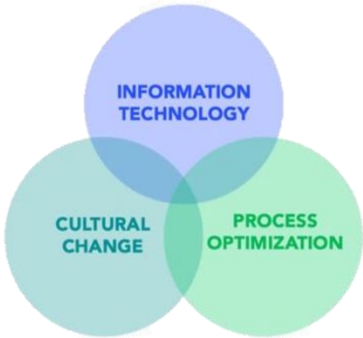


Figure 4 *Venn diagram including the three main pillars of digitization*

Building up the Agile Squad

In a nutshell, agile management suggest the division of a functional company into small teams of employees[30]. Each one of these teams acts with autonomy but also with overall objectives aligned with the other teams of the company. Here the aim is to understand Agile management to change the way in which traditional IT department runs to meet the ever-changing demand of clinicians and healthcare providers across the hospital [31]. In the Agile Manifesto, is highlighted the key messages including self-organization, collaboration and cross-functionality of teams that are applied in the project of this text [32].

The individual teams that make up a company in agile management are usually known as squads. The aim is that each squad has its own defined goals, which they work towards autonomously. In this model each squad is a small multifunctional and self-organized team, acting like a start-up in its own right. The key to understand how the squad runs is autonomy. Each team has self-governance to decide what to do and how to implement those changes as well as the way of organization to achieve those goals. In the abovementioned meeting on the 08th of January (the seed stage of this project) one of my first tasks was to build the squad. The squad integrate three main profiles: clinicians, managers and technicians, each one with its objectives in short, mid and long-term.

The intensivist Dr Ricard Ferrer who is the Head of the Intensive Care Unit at the General Hospital and the president of the Spanish Society of Intensive Medicine supervised and monitored the outputs of the project. He also contributed to management knowledge in all ranges and levels. I support my daily work in Dr Marcos Perez, an associated intensivist at the ICU who contributed to the project with the vision of the on-duty and the critical-care researcher needs. He also validated all clinical concepts and indicators used to build the tool. It is important to recognize both of them as a key expert as well as end-users.

Following, the software engineer Ana Cía who helped me with the IT management along with the design of the tool. She also helped me with the technical implementation of the project with all the knowledge and expertise she had acquired during those lasts' years in the IT Systems Department of VHUH. After the end of May, Zaira Benítez substituted Ana Cía in all functions and duties concerning this project.

The manager profile was filled by Dr Jesús Martinez a long-experienced intensivist who was in charge of the coordination of the critical care units of VHUH, from neonates and paediatrics to burns and traumatological critical care units through the general adult's unit. He contributed to the project with an accurate vision of clinical management, use cases of current needs covering the future decision-making support tool and the demand that ICU runs synchronously with the rest of the hospital. Finally, Dra. Yolima Cossio the director of Information Systems in VHUH who monitor the project and guide all of us from the begging. She delegates reliance on me and follows the project through all these months establishing directories from design, development implementation, squad creation, and validation of the decision-making support tool described in this document.

Once the squad is presented, is relevant to detail about the responsibilities in terms of management I had during the project. I had the duty to prioritizes work to be done, schedule meetings and to work together with the rest of the squad members to achieve several milestones. I defined goals and created a vision for the development of the project and aligned it with the bachelor's thesis deliverables. I was also in charge of communicating if any problem needed to be solved outside the squad and do report to part of the hospital executive board. As a product owner, it was also important to work to align all the member of the team with a single mission and shared vision of the strategy of the product.

My first experience at the VHUH was job shadowing with the intensivists at the ICU. That exercise consisted in observing clinicians performing their job and was crucial to understanding how the unit works and how duties were conducted inside and outside the ICU. Job shadowing allowed me to acquire a detailed vision of internal processes and identify the main needs and bottlenecks. I identified three main profiles as potential users for the app (i.e. Table 2).

After this, I proceed by writing the needs and requirements document, a working document that was re-edited and approved in several periodic meetings with all the members of the squad. Once I had a clear idea of what the product was supposed to be, I finished this first step of defining the objectives by building the mock-up. A mock-up is a way of representing a product with a mid or high-fidelity display of design. The first mock-up was not clickable, but it allowed me to experiment with the visual side of the tool and ask for feedback to end-users (i.e. figure SI-1). Once all this work was done and validated by all the members of the squad, the next step of identifying and resolving risks was conducted.

User	Responsibilities
Head of ICU	Clinical management of physical resources and staff of ICU. Coordination inside and outside of the unit to work in concert with other units like the Surgical Block. Quality control and monitoring backup. Research leadership.
Attending Rounds Intensivist	Patient-centred care. Early stages of clinical research conducted at the campus (VHIR).
On-call Intensivist	Clinical Management of physical resources and personnel of unit. Patient-centred care.

Table 2 *Potential end-users*

2.2 Identifying and resolving the risks

Risk is described as an uncertain event or condition that if it occurs, has a positive or negative effect on the objectives of the project [33]. The identification of the potential risk is done while planning, before defining the objectives of the project and ends up with the de-risking strategy. While predicting the future with certainty is not possible, we can apply a simple and streamlined Risk Management Process (RMP) to predict the uncertainties in the project and minimize the occurrence or impact of these uncertainties [34]. In this text the RMP followed is based on Nokia Siemens Network that provides guidelines for continuous risk identification as well as risk mitigation and contingency. Is important to note that risk management *per se* is an iterative process and this exercise must be repeated for each iteration implemented in the development plan [35] .

The risk management plan includes the following: a list of possible risk sources and categories, the impact and probability of these risks, a risk reduction and action plan and a contingency plan. Risk identification was mainly conducted by a series of checklist analysis tables (i.e. section SI-2). Once the risk was identified and categorized, then it was analysed following probability of risk occurrence and risk impact (i.e. Figure 5). The results and conclusions of the risk analysis conducted are further explained in this text (i.e. section 3.2 “Risk Management”)

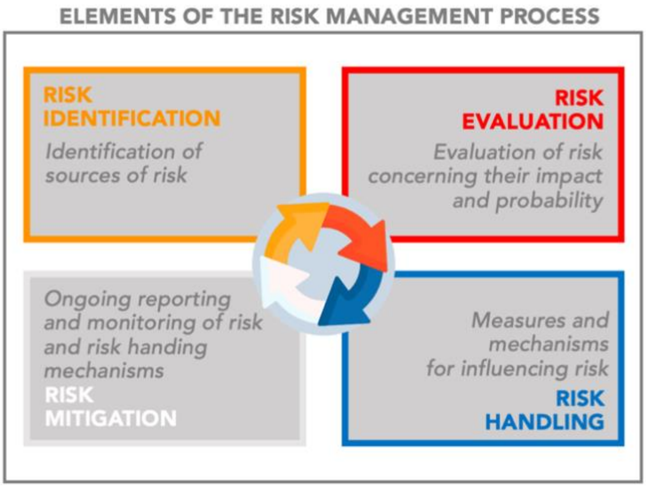


Figure 5 *Risk Management Process containing the four main steps to iterate: risk identification, evaluation, handling and controlling.*

2.3 Engineering Stage

The engineering stage was by far the most consuming part of the project consisting in programming, coding and the deployment of the software solution. Before explaining this stage in detail, is important to mockup the fundamental building blocks of a BI architecture (i.e. Figure 6) [36]:

- A source System.
- An extraction, transformation and loading (ETL) process.
- A data warehouse.
- A BI platform such as MicroStrategy.

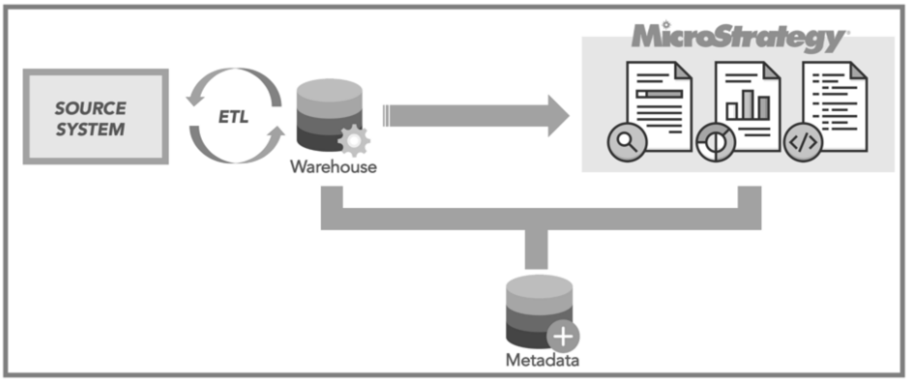


Figure 6 Diagram illustrating the setup for standardizing data from the source system and transferring that data into MicroStrategy.

2.3.1 Source System

Source system refers to any system or file that capture or hold data of interest. A source system is usually the most significant site of an online transaction processing (OLTP). These OLTP are basically databases or mainframes that store real-time processing data where data access is optimized for frequent reading and writing as the system records huge volumes of data per unit of time.

2.3.2 ETL

The ETL process represents all the steps necessary to move data from different source systems to an integrated data warehouse. It involves the following steps:

1. Data is gathered from various source systems. In this project, data was gathered from different tables and lists created in the Centricity Critical Care system at the ICU.
2. The data is transformed and prepared to be loaded into the data warehouse. In this project transformation procedures included converting data types and names, eliminating unwanted data that was not relevant for clinical management purposes or was redundant, correcting data identification, filling incomplete data and merging several data systems. These similar processes were done to achieve a standardized format and structured data.
3. Last, data is loaded into the data warehouse.

Taken as a whole, the ETL process consolidates data so it can be stored in the data warehouse. A well designed and robust data warehouse is the source of data for the decision support system or business intelligence system beyond. Data warehouses are usually based on relational databases or some form of relational database management systems (RDBMS) platform. These relational databases were queried directly with Structured Query Language (SQL) a language developed specifically to interact with RDBMS software. I structured the ETL in two main jobs that will be executed periodically. The first one will be constantly updated since data from patients is being refreshed almost every minute and the second one is going to be updated weekly because it contains information about historic patients that rarely is updated. For more information about the structure of jobs and transformations further information as well as their building blocks are found in this text (i.e. SI – 3).

2.3.3 Data Warehouse and MicroStrategy

From all the BI solutions in the market, MicroStrategy was the one selected for VHUH mainly for two reasons: security of data and the ability to build self-service analytics. Security is a major concern in any company, but it becomes critical in healthcare organizations. Personal health information needs to be protected from unauthorized access to prevent being tampered with, destroyed or disclosed to others. MicroStrategy implements a robust security model that enables to create users and control what data they can see and what objects they can use. Authentication is the process by which the system identifies the user and it is an integral part of the security model. The authentication in MicroStrategy allows the administration to make the right data visible to the right users to prevent that some of the sensitive information contained in the data warehouse is not being jeopardized. The other reason why MicroStrategy was elected among competitors is the ability that users have to easily build reports. Self-service analytics empower healthcare employees, and the enterprise alike, to see and understand data across every hospital system (operational, financial and clinical). With direct access and the ability to explore stratified data, any healthcare worker can monitor, measure and understand any related clinical outcome with data. A MicroStrategy system is built around a four-tier structure (i.e. Figure 7).

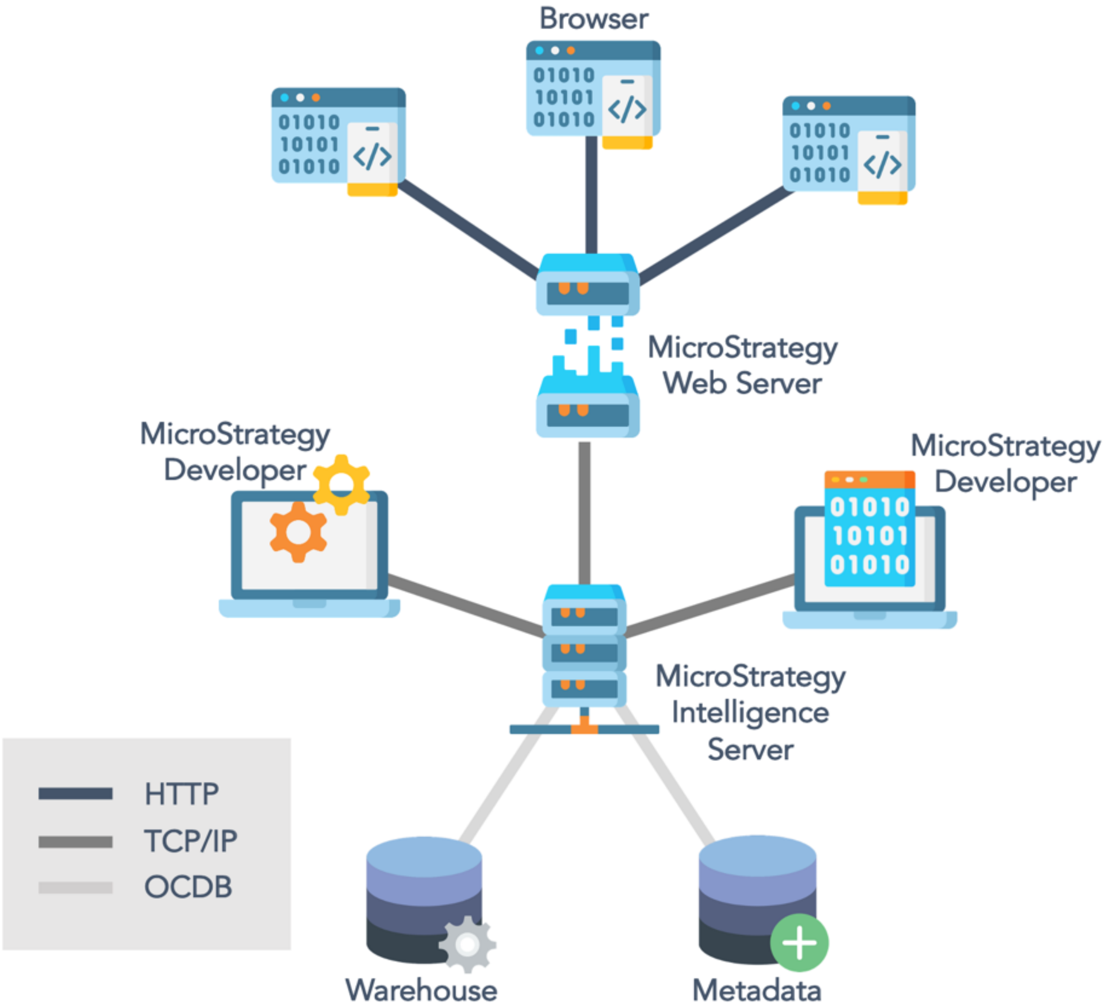


Figure 7 Diagram of the four-tier structure implementing the BI solution in the document.

In figure 7 ODBC correspond to Open Database Connectivity, a standard API for accessing database management systems (DBMS); TCP-IP are the communication protocols used on the internet and similar computer networks and, Hypertext Transfer Protocol (HTTP) stands for the application protocol for distributed collaborative hypermedia information systems.

I. The first tier (at the bottom part of figure 7) consists of two databases: the data warehouse, which contains the information that the user analyzes; and the MicroStrategy metadata, which contains information about MicroStrategy projects.

Data Warehouse

The data warehouse is the foundation that MicroStrategy system is built on. It stores all the information to analyze with the MicroStrategy system. This information is usually placed or loaded in the data warehouse using some sort of ETL process (explained in section "2.3.2 ETL"). The online transaction processing (OLTP) system is usually the main source of original data that the ETL process uses. The system administrator knows which relational database management system (RDBMS) does the data warehouse manage, how the MicroStrategy system accesses it (which machine it is on and which ODBC driver and Data Source Name it uses to connect to it), and what should happen when the data warehouse is loaded (such as running scripts to invalidate certain caches in Intelligence Server, and so on).

MicroStrategy Metadata

MicroStrategy metadata is like an index to the information that is stored in VHUH data warehouse. The MicroStrategy system uses the metadata to know where in the data warehouse it should look for information. It also stores other types of objects that allow you to access that information. To explain easily how the MicroStrategy system uses metadata to achieve the results, imagine that a user runs a very simple report with the total of patients from the ICU coming from the Surgical Block after a transplant of a solid organ in a quarter of the year. The metadata stores information about how the clinical metric is to be calculated, information about which rows and tables in the data warehouse to use for obtaining information about the surgical block or the patient group and the most efficient way to retrieve the information.

II. The second tier consists of MicroStrategy Intelligence Server, which is the heart of the MicroStrategy system. It executes reports stored in the metadata against the data warehouse and passes on the results of those reports to the users.

III. The third tier in this system is MicroStrategy Web or Mobile Server, which delivers the reports to a client. Some of the tasks in this tier were performed by Ana Cía, such as managing users and group privileges for Web or registering a project in server mode so it can be available in the web. Which allows me to develop indicators and attributes that were used later on in the MicroStrategy Web. For more information about the different variables build on in MicroStrategy Developer (i.e. SI-4).

IV. The last tier is the MicroStrategy Web client or MicroStrategy Mobile app, which provides documents and reports to users. This is where I spend most of the time configurating the report that builds the decision-making support tool. This task was non-coding, basically based on a drag and drop exercise to set up the different parts of the dashboard, information belonging to it and the visualization mode of this data.

2.4 Planning the next iteration

The evaluation of the outcomes of software projects has been the subject of unresolved debate for many years. In the SDM the evaluation is mainly done thinking in users. The evaluation of the project is based on the identification of factors of influence for the success of it and consequently, this section sets out the basis for the conclusions of this text. Criteria-based assessment is a quantitative assessment of software in terms of sustainability, maintainability, and usability. It can inform high-level decisions on specific areas for software improvement and gives a measurement of quality in a number of areas derived from ISO/IEC 9126-1 Software engineering — Product quality. This criterion was stablished by the Software Sustainability Institute in the UK [37].

In the SDM the measurement of outcomes is performed while iterations are accomplished. So, the test with criterions and sub-criterions must be done at the end of each iteration to check that sustainability, maintainability and usability are not compromised for the coming iterations. A formal project evaluation at the end of each iteration gives a clear indicator of how the project is performing against the original estimations and it can be also used to gran approval and planning for next iteration. The assessment criteria are settled as follows in the table in the annex (i.e. SI-5) and evaluation results are furthered discussed (i.e. Section 3.1 “Evaluation”).

3. RESULTS

The results disclosed in this text correspond to the latest version of the product obtained by the end of 5th of June. The discussion in this text, as well as the evaluation of the product performed in next sections, are based on this version of the product and all its limitations. Hence, the results presented (i.e. Figure 8)[2] reflect two sets of achievements:

(A) Back-end achievements

- Fully understanding of how the data source was structured and managed and correlate the data with the clinical variables identified (i.e. SI-4).
- Creation of a functional ETL in a development stage tested and ready to move to production. Ensuring the viability and maintenance of the product by efficiently creating several jobs and transformations.
- Creation and definition of a set of indicators and attributes in MicroStrategy Developer that can be used for this project or others.

(B) Front-end achievements

- Display of a total of 30 simple or simple variables from a total of 40 initially proposed. Including patient ("ID, NHC, Box, Unitat, PNP Aïllament, Tipus d'Aïllament, Germen, Nom, Cognoms, Sexe, Grup de Pacient, Edat, Dies UCI, Data Ingrés Unitat, Data Alta Unitat, Indicador Cens o Històric, Origen, Destí, NAS, Pao2/Fio2, Spo2/Fio2, Assistència Ventilatoria, TCRR, RASS, Drogues Vena-actives and GCS Ocular, Verbal, Motor" as well as the aggregated variables "Cens de pacient, Grup de Pacients, Grup de Pacients Ventilats, Aïllament") and excluding ("Diagnòstic Principal, Diagnòstics Secundaris and Procediments and GCS total" as well as the aggregated variables "Ocupació de la unitat, NAS Global, Estat de la unitat per sectors").
- Good performance of the tool in the stress test implemented.
- Good level of user experience and accurate representation of the interface that will display the final functional product.

[2] Note that the columns in Figure 8 corresponding to "Patient ID", "Name" or "Surnames" were not disclosed in this text regarding patient privacy.

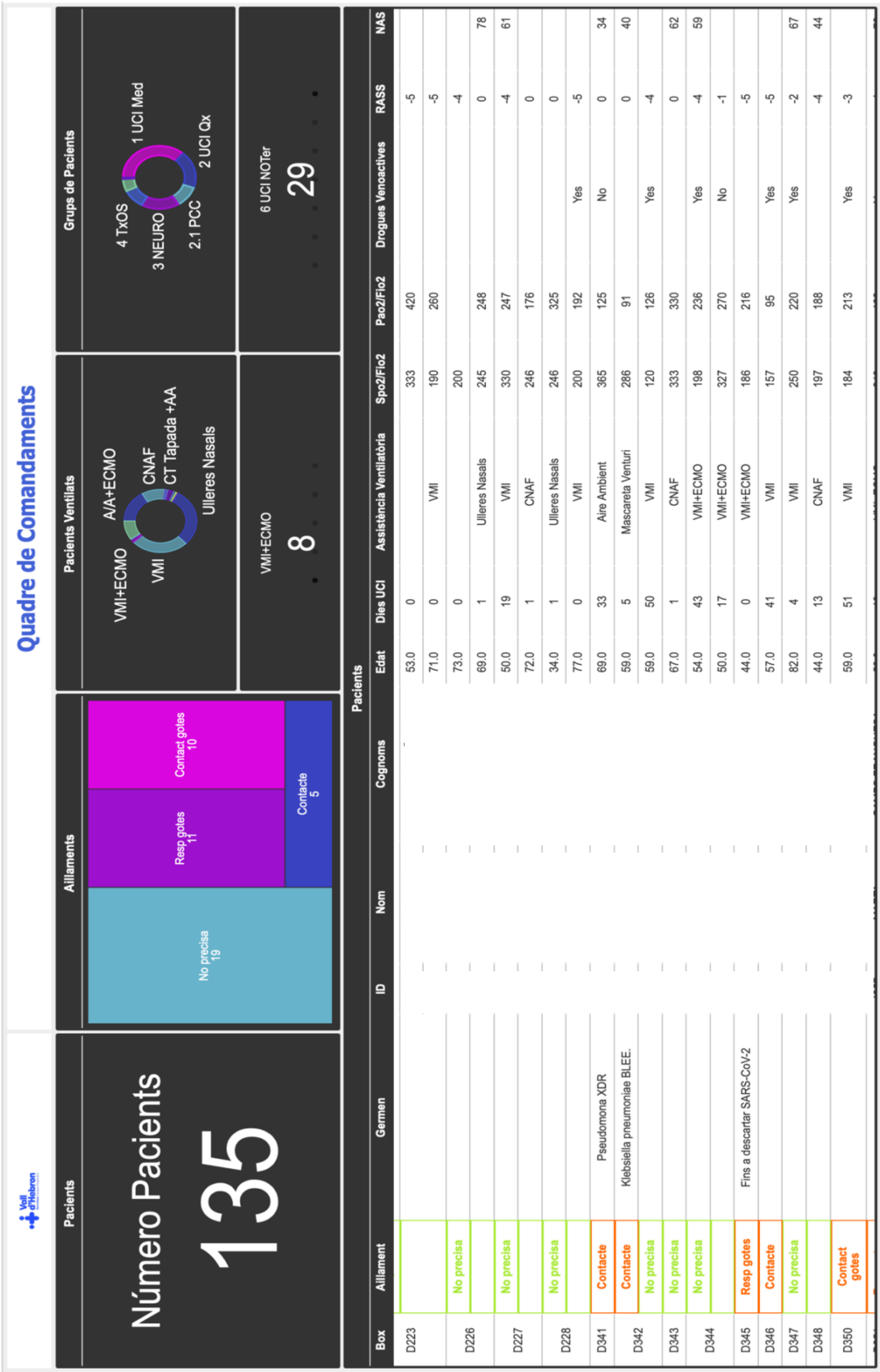


Figure 8 Principal view for the intensivist of the decision-making support tool for the Smart ICU of the Vall d'Hebron University Hospital in MicroStrategy Web.

3.1 Evaluation

The reasons of performing an evaluation of the software are explained in (i.e. section "2.4 Evaluation, Planning the next iteration"). Therefore, in this section a close insight about the evaluation for the particular results obtained is exposed following the set of criterions chosed (i.e. SI-5).

Usability compromise how easy to use and how much optimized the software is and, if the software looks professional and trustworthy. The latest version of the product achieved a good level of usability. Documentation regarding the design and implementation of the tool is comprehensive, well-structured and detailed. Data displayed in the software are based on clinical indicators of patient's health status. Identity of the project is unique and design strategy follows user experience (UX) philosophy and the digital VHUH guidelines (i.e. section 3.1.1. User Experience design). Access to the tool is guaranteed from multiple web browsers and information can be easily downloaded in a .pdf file. This ensure information where, when and how the user wants.

The product is expected to have high cost of maintenance because a continuous development and deployment phases are needed. Cost of maintenance analyzed does not even consider the MicroStrategy license agreement. Privacy and security requirements explained in detail (i.e. Section "2.3.3 Data Warehouse and MicroStrategy") certificate the highest level of security against any unlawful access to private information. This has been one of the major concerns from the begging of the project since sensitive information about patients is managed in the software. One of the main advantages of the project is that once a third iteration is achieved, will be relatively easy to make minor changes to the MicroStrategy Web Service, such as add new field to the data source or preference choices as filters and indicators without a huge development effort. Moreover, data source of MicroStrategy can be migrated to other system if needed.

3.1.1 User Experience design

The product released achieved a good level of user experience (UX) or human to machine interaction, which is essential for the successful implementation of a tool like the one presented here [38]. First of all, the product is correctly embedded in the process for which is designed for, intensivist's routine and ICU's processes. Early versions of the product as well as the methodology followed to design it avoid the overengineering of the tool, something that at the end can backfire the product and be counterproductive. One of the main concerns in the developing stage was the efficiency in coding and optimization in programing that, in UX is translated into a fast to extract relevant information interface [39]. This was mainly done because users' interface that are frustrating to use can lead to customer desertion. Among some of the UX designs principles reflected in the product are:

- Simple and easy principle. Since in this version unnecessary complexity is avoided, simplicity will be a standard for all further iterations. The user's cognitive workload is being reduced whenever possible. For future iterations of the tool, the user's interface should be consistent, stable and intuitive and a clear visual hierarchy with other functionalities or views should be established.
- Contextual principle. The user is contextually aware of where he or she is within the system, by text titles along with the scores boxes of the tool.
- Engagement Principle. In this release of the product, user is fulling engaged by delivering value and providing a strong information sense. This principle is ensured by involving the users in the early development stages.
- Beauty and delight principle. The tool is enjoyable and makes the user want to use the system.

3.2 Risk management

The purpose of conducting a risk identification, a risk analysis and implementing a mitigation strategy for the project is explained in detail in methods section where the identification and analysis criteria are further introduced, for detailed information see section (i.e. Section "2.2 Identifying and resolving risks"). Therefore, in this section a close insight about the risk management performed is exposed. Based on the elements in the risk management criteria (i.e. SI-2), the following paragraphs must be understood as the risk identification and analysis as well as a light summary of the mitigation proposal. The first set of risks identified was related to the creation of the working team. I had never worked before with any of the professionals involved in the team, but that was an inherent risk with low impact in the project. Moreover, some of the members of the squad belonging to the end-user clinical profiles did not have a deep insight into the engineering process, development of software or programming skills. The lack of knowledge identified could generate frustration about the results obtained and for so, this was identified as high probability and high impact risk. A strategic presentation about the

SDM was done before starting the collection of needs, the raise of awareness about the advantages and disadvantages of this methodology was crucial for creating a good working environment based on professional confidence.

The second set of risks identified was associated with the technology to be deployed. The complete lack of documents explaining previous experience in the design and development of tools like the one presented in this document was ranked as a high impact risk. The creation of tables, coding explanations, interaction maps and this text by itself ensure the viability of next iterations of the project and mitigate the related risk. At the begging of the collection of needs, end-users did not have any particular bias about the details of the final product, despite having a clear vision about the main needs it will have to cover. This starting scenario was qualified as a positive risk, then as well as other risks were mitigated by implementing correctly the spiral iterations in the SDM. A critical risk ranked as high probability and high impact was the creation of new algorithms that could imply a complex intelligent solution never developed before in VHUH. If that stage of development will be reached in next iterations, then a straightforward mitigation strategy should be implemented. High performance of the tool is listed as a risk because low performance would have a high impact on the usability of the tool. Despite all, this scenario is ranked in low probability because the MicroStrategy service had been tested before for the hospital in similar environments and loads.

Apparently, that all the members of the squad were not full-time dedicated to the project was something not relevant. The compromise between stakeholder was assured and by this the future of the project was clear, but oncoming events explained in detail (i.e. Section "4.3 Limitations") generated a huge negative impact in the project. Then, this risk identified and ranked as high impact, but low probability was not mitigated properly.

In addition, I can conclude in advance that despite the principal strategy to mitigate risks of the project was based on the SDM there are also some risk associated with this methodology: (a) The risk of not comply with planning, truly the initially of the project was rescheduled several times during the whole project; (b) The model usually works better with bigger projects than with little ones, the project presented in this text seems to fit the size required due to constant testing and deployment; (c) For a good implementation the spiral model should be followed strictly, in the sense that if spirals go indefinitely the mitigation risk is compromised.

4. DISCUSSION

4.1 Future work: Planning the next iteration

Heretofore two iterations were completed and a third one is expected to be concluded by the end of June. Fully accomplished or underway iterations comprehend: i) The first iteration when the mock-up was released, validated and forward feedback collected; ii) The second iteration included the kick-off of the MicroStrategy Web service with the current interface even though it was not fully functional yet; iii) The third iteration should ensure real-time capabilities that hold an effective implementation in the ICU with limited but reliable functionalities. Once a trustworthy tool is developed and tested, successive iterations get shorter in time, with small releases of improvements in the product. Next iterations should not take more than two weeks consolidating user’s engagement.

Further iterations around the development of the tool should contemplate the following vision: i) Start by deploying new indicators that will allow intensivist a deep insight about ICU performance. This iteration should include simple logics that calculate for example capacity of ICU by sectors; ii) Follow by endowing the tool with the so-called *intelligence* in BI, allowing clinicians to for example, identify in a straightforward way possible patient’s discharges; iii) End by starting a new uncovered need collection round that could be the seed stage of a new version of the tool. In this new stage, the possible impact of a BI tool like the one presented in this text should be considered in a broader sense compelling research, backup quality control or clinical trials. Further implications in terms of management and technological development requirements should be carefully inspected at that moment. In order to achieve future successful releases of software, the project must be prioritized inside the backlog of IT department giving the required resources when needed.

4.2 An agile operating model in healthcare

Has been proved that SDM is a good strategy to deploy the design and implementation of a tool such as the one proposed in this text. The methodology helps to understand clinical process, to identify uncovered needs and bottlenecks, to improve the development process, to manage risk and evaluate product progress and results. Nonetheless, SDM must be understood as an integral part of a vision embedding IT development, optimization of processes and cultural change. This methodology also forced to the designer and developer to document requirements, needs and objectives, to do a risk analysis, elaborate a mitigation plan and an evaluation criterion to check the results after each iteration. Those documents and plans are still missing in the majority of similar projects leaded inside hospitals, despite they have proven benefits in order to evaluate impact of the solution and efficiency of execution.

In my opinion, future iterations should follow the same methodology and keep bringing in practices form other methodologies such as scrum. When iterating the leader of the project works in a complex environment with fast changing needs and resources and this methodology has been demonstrated to be a good standard to manage risk. Nevertheless, daily implementation can be supported by practices from more traditional methodologies such as the waterfall model. With hindsight, agile operating model applied to IT, will become de rigueur for all management process inside the hospital, from planning to execution. As speed of execution will become a major source of advantage fueling this shift towards a more digital hospital. Senior leaders will have to rethink organizations structures, attracting and retaining talent policies, operating models and reskilling their employees in order to achieve tomorrow's healthcare systems.

4.3 Limitations

By the end of the second iteration, limitations of the product released were based on the lack of some variables and indicators relevant to achieve the holistic view of patients. Limitations also included a lack of a complete set of visualizations for quality control and backup monitoring of ICU performance. For more information regarding the unachieved objectives see (i.e. Section "3. Results"). Major limitations were due to the issues raised during the engineering stage, leading to a delay in the release of the second iteration of the product. Those programming errors were mainly caused because data source structure inconsistencies and how data warehouse was managed in prior layers to product development. This unpredicted scenario generated inefficiencies during the ETL programing phase which led to cost overruns.

I could not overcome the constraints explained above fundamentally for two reasons: i) The pandemic scenario outbreaking by mid-March 2020 that had an estimated impact of one month of work causing a delay in both the final approval of needs and the begging of the development stage[3]; ii) The loss of BI Lead supporting the development of the tool in

[3] Despite that the risk associated with the scenario described was initially classified as low possibility, the outbreak of COVID-19 in March 2020 in Spain had a huge impact on the viability of the project. Please note that the squad involved a set of intensivist, engineers, managers and members of the executive board

two crucial periods of the engineering stage causing an estimated delay of one and a half month of work. This loss caused a drain of talent and expertise in all ranges that compromise even future stability and scalability of the project.

4.4 Conclusions

About the product development:

- It has been achieved the development and deployment of a not fully functional version of the decision-making support tool designed. The clinical management information system delivered, aggregate comprehensive data, prioritize relevant information and integrate it back to existing critical care unit's workflows. It represents a good approximation to a tested and validated product that could enable faster and more informed decision-making.
- It has not been proofed the real impact of the tool in terms of efficacy and efficiency in the ICU due to limitations of the developed version. Anyway, a reliable development pipeline and evaluation criteria are outlined in this text.

About the data:

- The usability and trustworthiness of the tool rely on the data displayed. Despite this, data can be corrupted unintentionally and any filter neither from digital nor human nature is applied. For so, the need for an intelligent filter able to discern true data from the corrupted one is real.
- On this matter, we as engineers, developers, researchers, business leaders, consumers and patients have to be aware that data are just data. When talking about achieving a holistic view of a patient, is essential to see the patient, touch the patient and explore the patient because subjectivity expression in medicine is still fundamental to achieve a better care. By this, an overload of data must be avoided.

About the management model of the project:

- Here has been proved that SDM is a good strategy to deploy the design and implementation of a tool such as the one proposed.

of the VHUH who focused on redesigning hospital circuits, transform spaces, elaborate protocols, coordinate medical equipment's and take care of acute patents of highest complexity.

- It was eventually demonstrated that if a project is prioritized but no resources where assigned to it, it seriously compromises its future success. The prioritization should be done in agreement of both clinicians and engineering teams, operating under a single vision. It was eventually demonstrated before that without their complicity in participation, results in terms of true efficiency could not be achieved.
- Resistance to change, due either to distrust of a model whose execution has not been fully performed or the fear of losing status by professional relevance is at the heart of many frustrated projects, despite I have never seen the slightest hint during those months, it is something to keep always in mind. BI is not a miracle, for that reason is important to be realistic from the begging. Otherwise we could find ourselves in the paradoxical situation of subjecting the ICU to a complex and possible convulsive process of digitization only to find that we have replaced an obsolete way of working with a useless one.
- Finally, it is important to understand that patient care must be improved, professional burnout reduced, and personnel satisfaction increased in this order or, clinical management will merely be a theoretical and vain exercise.

4.4.1 Inspirations to reshape healthcare

Public healthcare is one of the major success stories of our times. But demand is driven by a combination of unstoppable forces: aging of population, changing patient's expectations and generational conflict, burnout of professionals and a predicted shortfall of physicians and nurses in the next ten years, all while healthcare costs are spiraling out of control. Regarding those challenges a simple but rational link can be assumed, higher costs implies higher expenses. But this is not necessarily true, in the complex pace of hospitals more efficient systems can keep health costs down so, without major structural and transformational change, healthcare systems will struggle to remain sustainable. For that reason, we need to set standards for digitization, data quality and completeness, data access and governance, risk management, security, system interoperability and adherence to standards. And this change would undoubtedly be easier to start from simple, agile and flexible structures.

Overall this text highlights the general excitement of Europe-wide stakeholders to build and ensure the delivery of ethical and trustworthy software tools that can support real improvements in care outcomes. Less than a decade ago, BI was celebrated as a game changer in the industry, here it has been outlined that it can increase productivity and efficiency of care, which allows healthcare systems to provide more and better care. In addition, it can help improve the experience of healthcare practitioners, enabling them to spend more time in direct patient care and reducing burnout.

Now COVID-19 pandemic is pushing against structural barriers that had previously slowed innovation in health systems. The ultimate objective from this post-pandemic scenario and the threat of a next economic recession is not to survive but, to emerge differently stronger from it. We will have to move faster to drive step-change improvement in operating costs and particularly automation and analytics in order to keep healthcare as one of the major success stories in modern times.

5. LIST OF FIGURES

Page.

6. LIST OF TABLES

Page

7. BIBLIOGRAPHY

[1] S. Gentry and P. Badrinath, “Defining Health in the Era of Value-based Care: Lessons from England of Relevance to Other Health Systems,” *Cureus*, vol. 9, no. 3, 2017, doi: 10.7759/cureus.1079.

[2] E. Nolte, H. Kluge, and J. Figueras, “World health Organization (WHO)/European Observatory on Health Systems and Policies. How do we ensure that innovation in health service delivery and organization is implemented, sustained and spread?”

[3] H. Thimbleby, “Technology and the future of healthcare,” *J. Public health Res.*, vol. 25, no. 6, pp. 402–403, 2013, doi: 10.1016/0039-6257(81)90081-3.

[4] E. P. Balogh, B. T. Miller, and J. R. Ball, *Improving diagnosis in health care*. 2016.

[5] T. O. Supp, O. R. T. Critic, and A. L. Decisions, “CentricityTM High Acuity Care software.”

[6] OECD, “Fostering Innovation in the Public Sector.” 2020.

[7] F. J. da Silva Ramos and J. I. Fiueira Salluh, “Data-driven management for intensive care units,” vol. 19, no. 1, pp. 19–23, 2019.

[8] M. Sánchez-Casado *et al.*, “Escalas pronósticas en la disfunción multiorgánica: Estudio de cohortes,” *Med. Intensiva*, vol. 40, no. 3, pp. 145–153, 2016, doi: 10.1016/j.medin.2015.03.005.

[9] J. A. M. Altafin *et al.*, “Nursing activities score and workload in the intensive care unit of a university hospital,” *Rev. Bras. Ter. Intensiva*, vol. 26, no. 3, pp. 292–298, 2014, doi: 10.5935/0103-507X.20140041.

[10] R. P. Moreno and A. P. Nassar, “Is APACHE II a useful tool for clinical research?,” *Rev. Bras. Ter. Intensiva*, vol. 29, no. 3, pp. 264–267, 2017, doi: 10.5935/0103-507X.20170046.

[11] Deloitte Insights, “Predictive analytics in health care Emerging value and risks,” doi: 19 july 2019.

[12] Y. K. Alotaibi and F. Federico, “The impact of health information technology on patient safety,” *Saudi Med. J.*, vol. 38, no. 12, pp. 1173–1180, 2017, doi: 10.15537/smj.2017.12.20631.

[13] J. M. Lillo Fernández de Cuevas and M. del C. Rodríguez Blas, “Estadística de

Gasto Sanitario Público 2018," *Minist. Sanidad, Serv. Soc. e Igual.*, pp. 1–18, 2020.

[14] Deloitte, "2020 Global Health Care Outlook," *Deloitte*, p. 2020, 2020.

[15] A. Börsch-Supan, "The impact of global aging on capital markets and housing," *Demogr. Chang. Ger. Econ. Fisc. Consequences*, vol. 34, no. 2008, pp. 65–88, 2008, doi: 10.1007/978-3-540-68137-3_4.

[16] and C. M. R. " Besheer, Zachary N., "Across the generations: responding to the baby boom healthcare leadership exodus," *Healthc. Financ. Manag. vol. 64, no. 1*.

[17] M. Canizares, M. Gignac, S. Hogg-Johnson, R. H. Glazier, and E. M. Badley, "Do baby boomers use more healthcare services than other generations? Longitudinal trajectories of physician service use across five birth cohorts," *BMJ Open*, vol. 6, no. 9, p. e013276, 2016, doi: 10.1136/bmjopen-2016-013276.

[18] J. Phua *et al.*, "Intensive care management of coronavirus disease 2019 (COVID-19): challenges and recommendations," *Lancet Respir. Med.*, vol. 8, no. 5, pp. 506–517, 2020, doi: 10.1016/S2213-2600(20)30161-2.

[19] Jorge Fernández Garcí, A, Solveigh Hieronimus, Angela Spatharau, J.-P. Beck, and J. Jenkins, "Transforming healthcare with AI," *McKinsey Co.*, no. March, p. 134, 2020.

[20] J. C. Lax, "Institut Català de la Salut - Memòria 2018," pp. 10–12, 2018.

[21] Vall d'Hebron University Hospital, "Vall d'Hebron Unversity Hospital Figures," 2020. .

[22] A. Rayes, *Internet of Things From Hype to Reality: The Road to Digitization*. 2020.

[23] V. Kanagachidambaresan, G.R., Anand, R., Balasubramanian, E., Mahima, *Internet of Things for Industry 4.0: Design, challenges and Solutions*. Springer Berlin Heidelberg, 2020.

[24] J. Ryan, B. Doster, S. Daily, and M. Heslin, "Soft innovation as data-driven process improvement exploited via integrated hospital information systems," *Proc. Annu. Hawaii Int. Conf. Syst. Sci.*, pp. 1–10, 2008, doi: 10.1109/HICSS.2008.405.

[25] J. Roche, "¿Qué es el desarrollo en Espiral?," *Deloitte Insights*, 2019. [Online].

Available: https://www2.deloitte.com/es/es/pages/technology/articles/que-es-el-desarrollo-en-espiral.html.

[26] B. W. Bohem, “A spiral model of software development and enhancement,” 1988.

[27] T. Codegiant, “Software Development Life Cycle — The Ultimate Guide [2020].” .

[28] M. Alawairdhi, “Agile development as a change management approach in software projects: Applied case study,” *Proc. 2016 Int. Conf. Inf. Manag. ICIM 2016*, no. December, pp. 100–104, 2016, doi: 10.1109/INFOMAN.2016.7477541.

[29] J. Whitehurst, “Can a culture of change improve innovation?,” *Washigt. Post*, 2019.

[30] M. Huskins, S. Van Kuiken, and S. Velemoor, “Applying lean IT to healthcare,” *McKinsey Co.*, no. December 2014, 2014.

[31] S. L. R. Vrhovec, “Agile development of a hospital information system,” *2016 39th Int. Conv. Inf. Commun. Technol. Electron. Microelectron. MIPRO 2016 - Proc.*, pp. 416–421, 2016, doi: 10.1109/MIPRO.2016.7522179.

[32] Agile Alliance, “Agile Manifesto,” p. 2019, 2015.

[33] P. Weaver, “The meaning of risk in an uncertain world,” *PMI® Glob. Congr. 2008—EMEA*, 2008.

[34] D. Hillson and D. T. Hulett, “Assessing risk probability: alternative approaches.,” *PMI® Glob. Congr. 2004—EMEA*, 2004.

[35] P. L. Bannerman, “Risk and risk management in software projects: A reassessment,” *J. Syst. Softw.*, vol. 81, no. 12, pp. 2118–2133, 2008, doi: 10.1016/j.jss.2008.03.059.

[36] MicroStrategy Inc, “Project Design Online: Introduction to MicroStrategy Architecture,” 2005.

[37] M. Jackson, S. Crouch, and R. Baxter, “Software evaluation: criteria-based assessment,” *Softw. Sustain. Institute, …*, pp. 1–13, 2011.

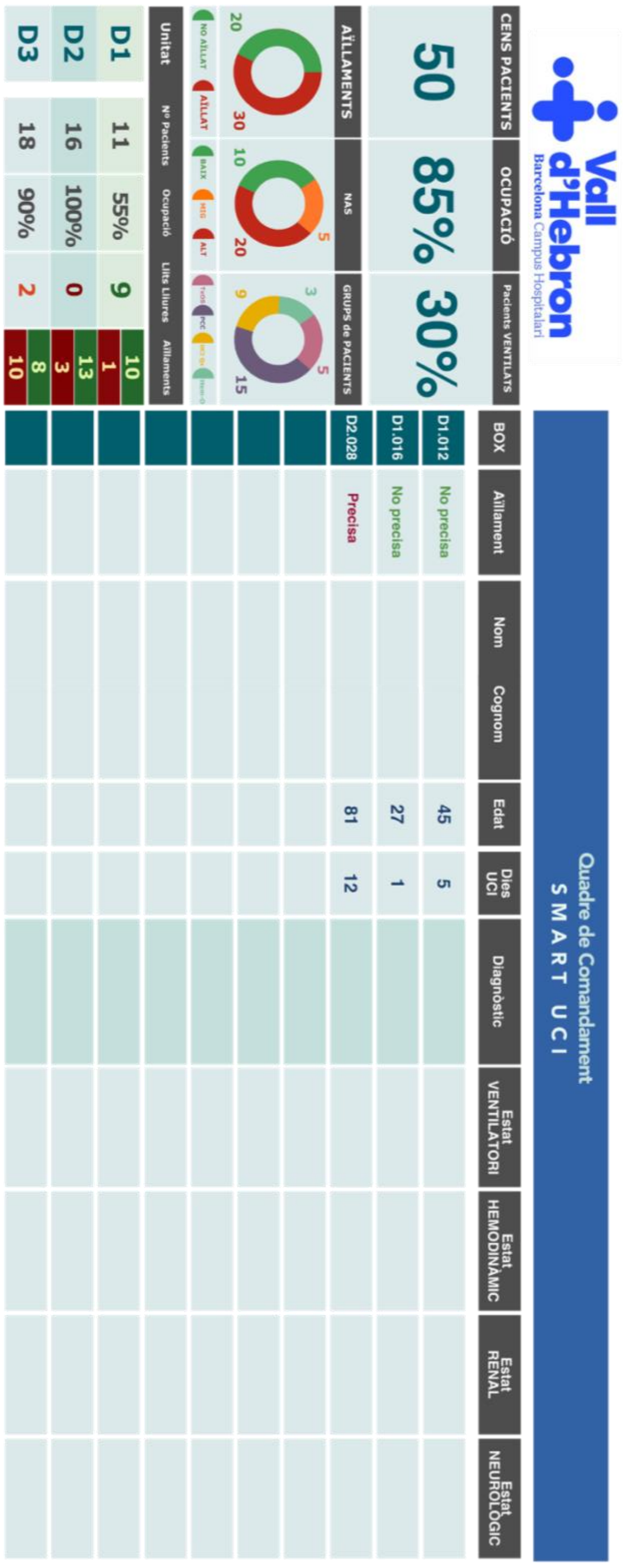
[38] R. Unger and C. Chandeler, *A project guide to UX design: For user experience designers in the field or in the making*. Pearons Education, 2012.

[39] L. Plonka, H. Sharp, P. Gregory, and K. Taylor, “UX design in agile: A DSDM

case study," *Lect. Notes Bus. Inf. Process.*, vol. 179 LNBIP, pp. 1–15, 2014.

8. APPENDICES

8.1 Mockup (SI-1)



8.2 Risk Identification and Risk Analysis Criteria (SI-2)

Here the criteria for risk identification and analysis is shown in a table format containing:

(a) Risk identification: Check point result and if it represents or not a risk.

(b) Risk Analysis: Impact and probability of occurrence of the risk identified before.

ID	Check Point // Defect Statement	Check Mark the appropriate Column		RISK	IMPACT	PROB
		Yes	No			
Generic risks associated with different users:						
2	Have you worked with the users before?					
3	Does the user have a solid idea of what is required?					
4	Will the user agree to spend time in informal requirements gathering meetings to identify project scope?					
5	Is the customer willing to establish rapid communication links with the developer?					
6	Is the user willing to participate in reviews?					
7	Is the user technically sophisticated in the product area?					
8	Does the customer understand the software engineering process?					
9	Does user's resistance to change? Or there are users with negative attitudes towards the project?					
10	Do may occur conflicts between users? Or lack of cooperation between users?					
Technical risks:						
11	Are facilitated application specification techniques used to aid in communication between the user and developer?					
12	Are specific methods used for software analysis?					
13	Do you use a specific method for data and architectural design?					
14	Is more than 90 percent of your code written in a high order language?					
15	Are specific conventions for code documentation defined and used?					
16	Do you use specific methods for test case design?					
17	Are software tools used to support planning and tracking activities?					
18	Are configuration management software tools used to control and track change activity thought the software process?					
19	Are software tools used to support the software analysis and design process?					
20	Are tools used to create software prototypes?					
21	Are software tools used to support the testing process?					
22	Are software tools used to support the production and management of documentation?					
23	Are quality metrics collected for all software projects?					

24	Are productivity metrics collected for all software projects?					
	Generic Risks associated with the technology to be built:					
25	Is the technology to be built new to your organization?					
26	Does the project imply a high level of technical complexity?					
27	Does the project imply an immature technology?					
28	Do the customer's requirements demand the creation of new algorithms, input or output technology?					
29	Does the software interface with new or unproven hardware?					
30	Does the software to be built interface with vendor supplied software products that are unproven?					
31	Does the software to be built interface with database system whose function and performance have not been proven in this application area?					
32	Is a specialized user interface demanded by product requirements?					
33	Do requirements for the product demand the creation of program components that are unlike any previously developed by your organization?					
34	Do requirements demand the use of new analysis, design or testing methods?					
35	Do requirements demand the use of unconventional software development methods?					
36	Do requirement put excessive performance constraint on the product?					
37	Is the user uncertain that the functionality requested is doable?					
	Generic Risks associated with development environment					
38	There is an inadequate estimation of required resources?					
39	There Is poor project planning?					
40	Are project milestones not clearly defined?					
41	Is a software project management tool available?					
42	Is a software process management tool available?					
43	Are tools for analysis and design available?					
44	Do analysis and design tools deliver methods that are appropriate for the product to be built?					
45	Are compiler or code generators available and appropriate for the product to be build?					
46	Does the environment make use for database or repository?					
47	Are all software tools integrated with one another?					
48	Have members of the project team received training in each of the tools?					
49	Are local experts available to answer questions about the tools?					
50	Is on-line help and documentation for the tools adequate?					
51	There are continually changing requirements?					
52	Is the system requirement not adequately identified?					

	Generic risk associated with staff size and experience					
53	Are the bet professionals available?					
54	Do these professionals have the right combinations of skills?					
55	Are enough professionals available?					
56	Are staff commitment for the entire duration of the project?					
57	Will some project staff be working only part time on this project?					
58	Have staff received necessary training?					
59	Will turnover among staff be low enough to allow continuity?					
60	Does the organization undergo restructuring during the project?					

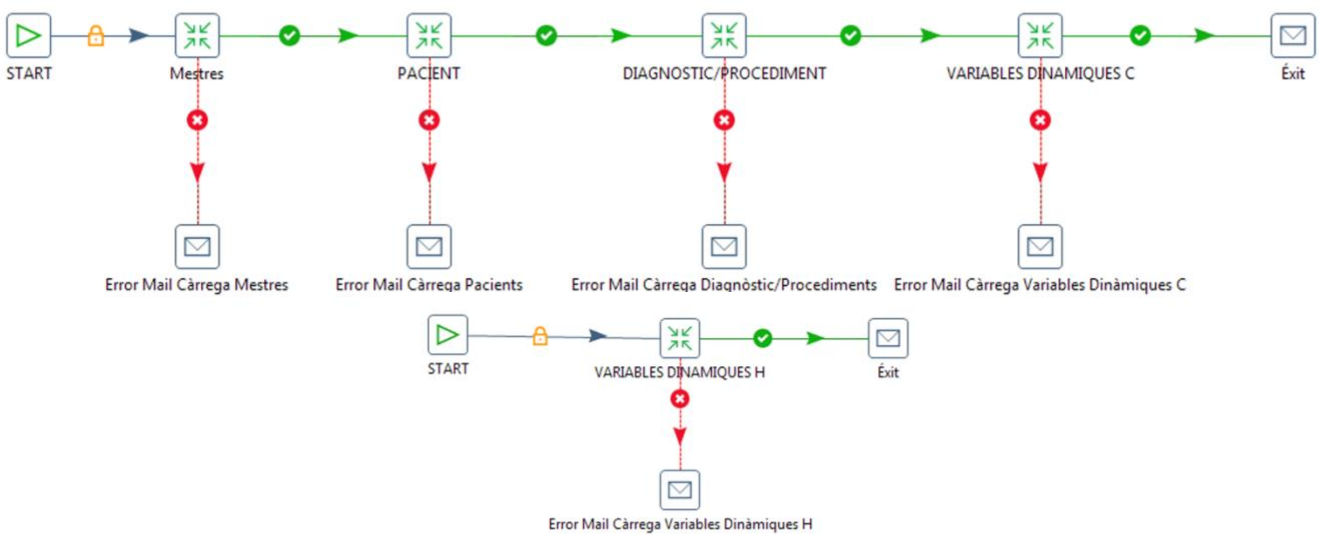
Table SI-2. Legend of labels to mark the risk analysis and the parameters to score severity.

LABEL	Probability of occurrence	Impact on Schedule
LOW	1-5%	< 1 WEEK
MEDIUM	6-10%	2 weeks
HIGH	11-20%	1 month
VERY HIGH	<20%	< 1 month

Legend SI-2. Legend of labels to mark the risk analysis and the parameters to score severity.

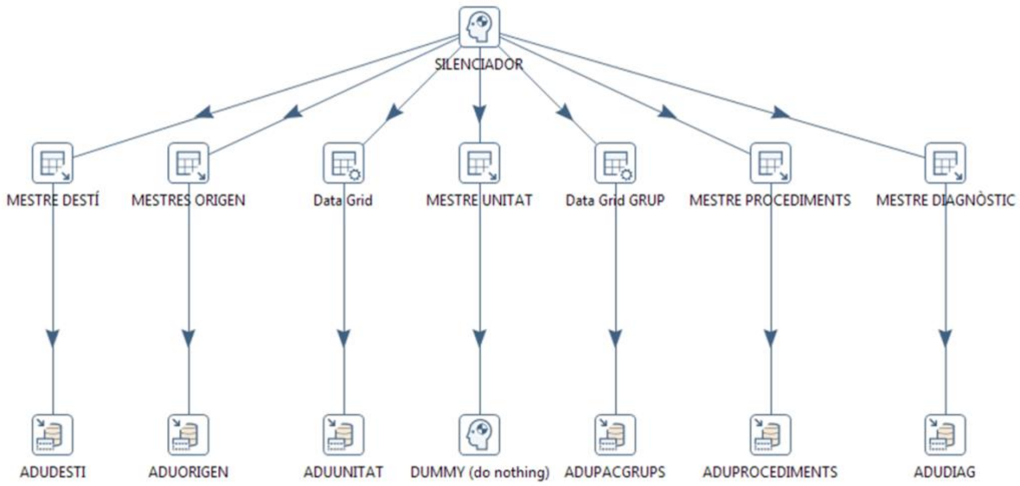
8.3 ETL (SI-3)

8.3.1 SI-3-1 Jobs

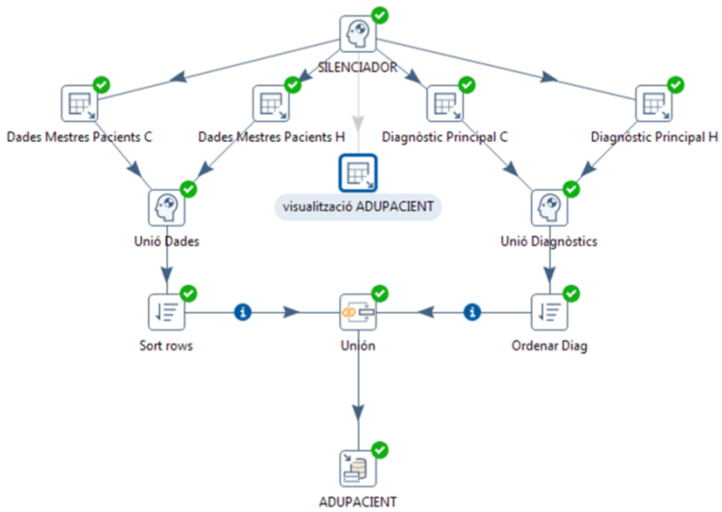


8.3.2 SI-3-Transformations

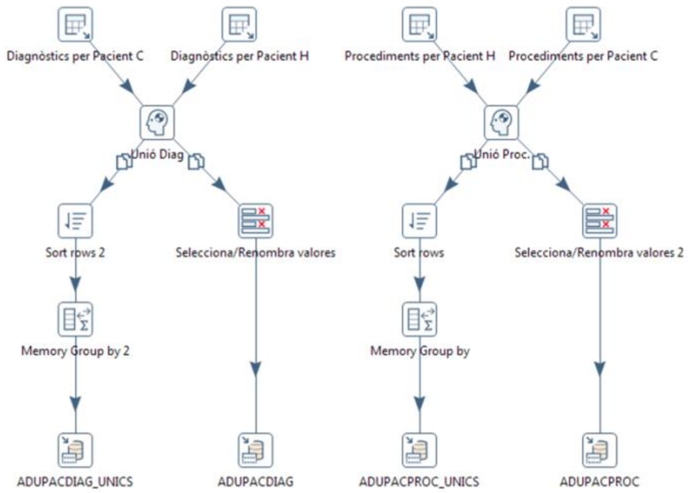
SI-3-T: Mestres



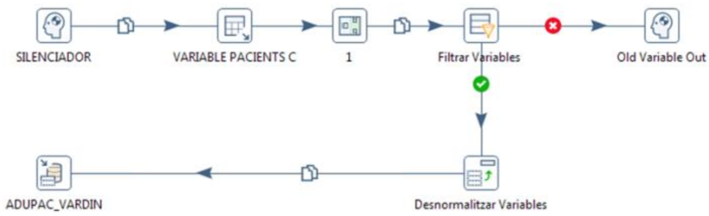
SI-3-T: Dades del Pacient



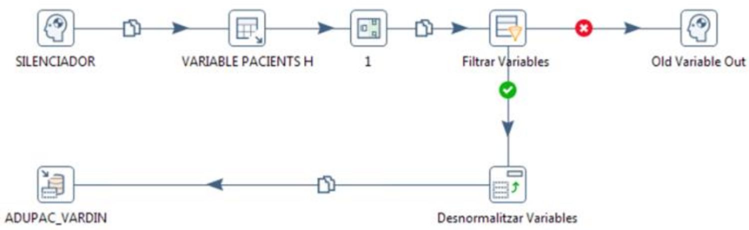
SI-3-T: Diagnòstics i Procediments



SI-3-T: Dades dinàmiques del Pacient en Cens



SI-3-T: Dades dinàmiques del Pacient en Històric



8.4 Simple/Aggregated Variables in MicroStrategy Developer (SI-4)

Identificador CCC	Identificador a MicroStrategy	Format	Descripció de la Variable
PatientID	Patient ID	XXXX	Numero Identificador del pacient
PatientNumber	NHC	XXXXXXXX	Numero d'Història Clínica (NHC)

Roomname	Box	DXXX	Box en el que es troba el pacient
WardAbbr	Unitat	DX	Unitat en la que es troba el pacient
15002996*	PNP Aïllament	‘Precisa’ / ‘No Precisa’	El pacient precisa o no precisa aïllament
15002996	Tipus Aïllament	String	Tipus d’aïllament del pacient
15002421	Germen	String	Germen que provoca l’aïllament del pacient
PatientFirstName	Nom	String	Nom
PatientLastName	Cognoms	String	Cognoms
PatientSex	Sexe	‘F’ / ‘M’	Sexe
ICUdiagnosiscodeID	Diagnòstic Principal	String	Diagnòstic Principal
diagnostic_id from adupacdiag	Diagnòstics	String	Llista de diagnòstics secundaris del pacient.
procediment_id from adupacproc	Procediments	String	Llista de procediments del pacient.
PatGroupAbbr	Grup	String	Grup del Pacient
AdmissionAgeInCalYears	Edat	XX	Edat
ICU_days	Dies UCI	XX	Estada en dies totals d’UCI
AdmTime	Data Ingrés Unitat	DD/MM/AAAA	Data d’Ingrés a la unitat
Distime	Data Alta Unitat	DD/MM/AAAA	Data d’Alta a la unitat
PatientStatusID	Indicador Cens Històric	‘C’ / ‘H’	Indicador de Cens o Històric
AdmWardID	Origen	String	Origen del pacient
DisWardName	Destí	String	Destí del pacient
15005374	NAS	Valor Numèric	Nursery Activity Score (NAS) del pacient
30003400	Pao2/Fio2	Valor Numèric	Pa02/Fi02 (VMI)
30003500	Spo2/Fio2	Valor Numèric	Sp02/Fi02 (no VMI)
15003358	AssitenciaVentilatoria	String	Assistència Ventilatòria del pacient
10002407	TCRR	‘Si’ / ‘No’	TCRR: Teràpies continuades de reemplaçament renal.

15003713	RASS	Valor Numèric	Richmond Agitation-Sedation Scale (RASS)
10000100,10000200,10000300	GCS	String	Glasgow Coma Scale (GCS): Suma del GCS Ocular, Verbal i motor.
10002405	Drogues Venoactives	'Si' / 'No'	Portador d'una única droga venoactiva (NAD; DPM; DBT, Labetalol, Urapidil, etc.)

Identificador CCC	Nom	Format	Descripció de la Variable
NA	Ocupació de la Unitat	XXX%	Resta entre el total de llits de la UCI i el total de pacients al cens de la unitat per a trobar l'ocupació de la unitat.
NA	Cens Pacients	XX	Suma el nombre de pacients total de la UCI en 'C', per a saber el nombre total de pacients a la unitat.
PatGroupAbbr	Grups Pacient	'UCI Med' / 'UCI Qx' / 'PCC' / 'NEURO' / 'TxOS' / 'HEM-ONC' / 'UCI No Ter'	Suma el nombre total de pacients per a cadascun del grups mèdics: UCI Mèdic, UCI Quirúrgic, PCC, Neurològic, Transplantament d'Òrgans Sòlid, Hemato-Oncològic, UCI No Terapèutic.
15003358	Grups de Pacients Ventilats	'VMI' / 'CNAF' / 'UN' / 'Aire Ambient' / 'Venturi' / ...	Suma el nombre total de pacients per a cadascun del grups de pacients ventilats: Ventilació Mecànica Induïda / Cànula Nassal d'Alt Flux / Ulleres Nassals / Aire Ambient.
15002421	Aïllament	String	Especifica quants pacients de la unitat es troben en aïllament.
15003374	Nursery Activity Score (NAS)	Valor Numèric	Suma del NAS associat a cada pacient de la unitat, per a donar un score global de la unitat.
NA	Numero de pacients per unitat	XX	Numero de pacients per unitat en el cens de D1, D2, D3 per separat.
NA	Ocupació de la unitat	XXX%	Ocupació de la unitat per sectors: D1, D2, D3 per separat.
NA	Numero de pacients aïllats per unitat	XX	Càlcul que sorgeix de la suma dels pacients aïllats que es troben en els sectors D1, D2, D3 per separat.

NA	Numero de llits lliures per unitat:	XX	Càlcul que sorgeix de la resta dels llits totals per sector (D1, D2, D3) i l'ocupació d'aquests sectors.

8.5 Evaluation Criteria (SI-5)

CRITERION	SUB-CRITERION	SUB-CRITERION	Result	
			Yes	No
USABILITY Usability compromises that the software is easy to use by end-users, that it is optimized for users, it conforms to common standards of user's interface design and accessibility? Does it look professional and trustworthy for the audience?	Understandability	Easily understood?		
	Documentation	Comprehensive, appropriate, well-structured user documentation?		
	Installability	Straightforward to install on a supported system?		
	Learnability	Straightforward to build on a supported system?		
SUSTAINABILITY AND MAINTAINABILITY	Identity	Easy to learn how to use its functions?		
	Intellectual Property Rights	Project/Software identity is clear and unique?		
	Governance	Easy to understand how the project is run and the development of the software managed?		
	Maintainability	How easy is it to maintain the site on production, without outages, errors or issues requiring the developer to get involved?		
	Security/Privacy Protection	Based on the requirements, what are the security and privacy protections in place against unlawful access? Are there logs, password encryption, SSL certificates, or separation of personally identifiable information? Have common security processes been implemented against common hacking vectors, such as sanitizing your inputs?		
	Adaptability	How easy is it to make minor, common changes to the site? For example, how easy is it to add new fields to the database, add additional content or choices, or change the user interface?		
	Portability	Usable on multiple platforms?		
	Accessibility	Evidence of current/future ability to download?		
	Supportability	Evidence of current/future developer support?		
	Analyzability	Easy to understand at the source level?		
	Changeability	Easy to modify and contribute changes to developers?		
	Evolvability	Evidence of current/future development?		

	Interoperability	Interoperable with other required/related software? If the data in the database either needs to migrate to a new system or be exported/exposed to another system, is the data model structured in a way to make this easy?		