UNIVERSITÀ DEGLI STUDI DI TRIESTE

XXIX CICLO DEL DOTTORATO DI RICERCA IN INGEGNERIA E ARCHITETTURA

TECHNOLOGY AND SERVICE ASSESSMENT TOOLS IN HEALTHCARE

Settore scientifico-disciplinare: SSD ING-INF/06 Bioingegneria Elettronica e Informatica

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Contents

Abstract

The role of clinical engineers is rapidly changing and the economic constraints have pulled them towards new responsibilities to manage. Particularly, the assessment of health technologies has covered one of the most important areas among clinical engineers' duties. Different techniques and methodologies for technology assessment and improvement are available in the literature and they are currently in use within hospitals and healthcare facilities. However, scientific research and practical needs seem to be misaligned, causing misuse of scientific results due to the lack of tools easy-to-use from practical perspective.

This thesis aims at integrating methodologies, even derived from different sectors, for providing standardized and versatile tools that overcome the current issues, providing healthcare facility with a path to follow for choosing the best methodology to be used in diverse situations.

Different case studies are presented, in order to cover the wide range of possibilities within health technology assessment (HTA). Particularly, technology assessment was performed on medical devices using both Hospital-Based HTA for an existing technology and horizon scanning for designing an innovative solution. Then the assessment was extended to hospital services, with particular attention to clinical engineering services, using Multi-Criteria Decision Analysis. Process improvement methodologies were also considered and applied to sterilization service that was also studied and assessed integrating the classical HTA approach with Multi-Criteria Decision Analysis.

These studies allowed to identify a path useful from practical perspective and based on scientific approach aimed at helping healthcare professionals and clinical engineers to choose the best methodology in accordance to specific constraints and needs of particular situations.

Introduction

Clinical engineers' role is multifaceted, and they are in charge of diverse tasks, ranging from supervision of clinical engineering department, acquisition and management of medical devices, to the evaluation of health technology, as well as training of medical personnel and coordination of outside services and vendors. Clinical Engineering Departments are established in many hospitals worldwide, with the primary objective to provide a broad-based engineering program that addresses all aspects of medical instrumentation and system support.

However, the practice of Clinical Engineering has changed enormously from its early days to the present, mainly due to the economic pressures that hospitals face, and the rapid development of highly complex instruments (e.g., MRI systems, surgical lasers). For this reason, assessment, acquisition and use of new technologies have played an increasing important role for clinical engineers, pushing them towards operational areas. In addition to technology assessment, clinical engineers are increasingly involved in process improvement, exploiting different techniques and approaches (e.g., lean management) aimed at reducing wastes and improving quality of service. Indeed, today clinical engineers are becoming heavily involved in strategic planning, technology assessment, and process improvement.

However, even though many tools are currently in use, standardized and versatile methodologies for assessing technologies and improving processes are not available. This is due to the heterogeneity of healthcare context, in terms of specific constraints of hospitals, multitude of involved actors, and diversity of technologies.

The research conducted within the present thesis, aimed at exploring tools and methodologies currently available and testing their application on different health technologies and services, with the final goal of adapting existing tools to innovative methodologies, in order to provide easy-to-use tools based on scientific findings but actually useful for practical needs of healthcare end-users.

The document is structured as follow.

The research question paragraph describes the workflow followed in the present work and presents the main research question the study aimed to address.

The first chapter introduces the state-of-the-art in terms of tools currently used within the healthcare domain for assessing technologies and making decisions. Particularly, it focuses on Health Technology Assessment and Multi-Criteria Decision Analysis since they are increasingly used in healthcare domain, and they have been demonstrated to be reliable. Technology Assessment will be described starting from its origin, underlying further steps of its implementation within healthcare technologies. The term "health technology" will be described in detail, since it has been debated in the literature, and the aim of the present work was to apply assessment tools on diverse technologies available in healthcare settings, including also

technologies usually not included in Health Technology Assessment (i.e., hospital services). Among the Multi-Criteria Decision Analysis tools, PAPRIKA will be presented, since it has been demonstrated to be one of the easiest tools among the others from decision makers' perspective.

The second chapter focuses on assessment of medical devices. It is divided into two main sections. The first section presents a medical device already in the market, used for surgical operations. The assessment was conducted through Hospital-Based Technology Assessment, in an Italian hospital, driven from the need of finding the best technology to be used in thyroidectomy. The analysis was performed through the typical approach of Health Technology Assessment, and considering Break Even Point calculated on the constraints of the hospital. The second section follows an approach similar to Horizon Scanning: a particular methodology used within Health Technology Assessment dedicated to technology not yet in the market. A preliminary study for assessing the innovative technology is presented. The proposed solution was designed with the support of the Biomedical and Clinical Engineering Group of the University of Trieste: it aims to improve awareness of patients with chronic conditions, and it is described within this chapter.

The third chapter focuses on a different kind of health technologies: hospital services. Indeed, enlarging the definition of health technology, hospital services can be considered as health technologies as well or, at least, "technology assets" that may fall into the field of interest of Health Technology Assessment. This chapter is divided into three sections: the first one is dedicated to the assessment of a clinical engineering department of an Italian healthcare facility through the usage of Multi-Criteria Decision Analysis; the second one focuses on the implementation and combination of different approaches for process improvement (e.g., lean management, goal question metric), for describing and analyzing the process of surgical tools in an Italian hospital; the third section combines the acquired know-how of both Central Sterile Supply Department (CSSD) domain and Multi-Criteria Decision Analysis, through the application of PAPRIKA within a CSSD of an Italian health authority. Moreover, in the third section of this chapter, a comprehensive methodology for applying Health Technology Assessment through PAPRIKA in the specific context of hospital service is proposed.

The fourth section briefly describes how assessment of medical equipment is currently managed in Low Income Countries, underlining the major issues at the state-of-the-art, proposing a possible solution aimed at overcoming the main challenges.

In the last section, conclusions of the research are presented and a possible path for choosing the best methodology for assessing and improving health technologies is proposed.

Research question

The following questions, that reflect the workflow of the present thesis, are addressed in the present work:

- What are the current main challenges of using HTA?
- How health technologies with no available previous data can be assessed?
- What are the main differences in using HTA approach on different technologies?
- Can HTA approach be useful for designing an innovative health technology?
- How process improvement techniques can be applied within the healthcare domain?
- Can "health technology" definition be extended to hospital services?

The previous questions, together with the main challenges highlighted in the literature, brought at the definition of the following main research question:

- Is it possible to integrate methodologies, even derived from different sectors, for providing standardized and versatile tools that overcome the current issues for technology assessment and process improvement?

Chapter 1
Overall state-of-the-art

This chapter briefly introduces methods for assessing technologies increasingly used within the healthcare system. Indeed, decision makers' need of providing comprehensive and objective evaluation on technologies acquisition prioritization has been accompanied by the development of methods and tools such as Health Technology Assessment (HTA) and Multi-Criteria Decision Analysis (MCDA). The term "technology" has changed during years, enlarging its primary meaning. As a consequence, HTA has started to assess a variety of diverse technologies, with no standardized methods. On the other hand, MCDAs have started to be used and to be considered of support to decision makers for basing their decisions on solid and rigorous approach. In the recent years, the introduction of MCDAs within HTA has been increased, since it provides a prompt technology assessment, based on scientific findings, through a lean approach.

1.1. Technology Assessment

1.1.1. Origin of Health Technology Assessment

In the last decades, the market for health technology has been reinforced due to different factors such as advances in science and engineering, aging population, increasing prevalence of chronic diseases, providers' competition, and malpractice avoidance. On the other hand, the attention to reducing expenditure and, at the same time, improving quality of assistance, as well as balancing technological advances with the available resources, has become a huge challenge to be faced. The leading actors who influence the development, adoption, and diffusion of technologies are a widening group of policy makers working in the healthcare sector. In order to answer the demand of assessing technologies to be designed and adopted, and to help decision makers within this process, Health Technology Assessment (HTA) was developed and it is commonly used in different healthcare contexts.

Technology assessment (TA) arose in the mid-1960s with the purpose to assess technologies for their potential unintended and harmful consequences (e.g., effects related to chemical, industrial processes, pollution, and weather modification). Both direct (i.e., caused by technology itself) and indirect consequences (i.e., unintended social, economic, and environmental effects) were studied within the assessment [1]. Technology assessment was defined as "the systematic study of the effects on society, that may occur when a technology is introduced, extended, or modified, with emphasis on the impacts that are unintended, indirect, or delayed" [2].

Healthcare technologies were among the topics of early TAs [3]. Technologies that evoke social, ethical, legal, and political concerns have been the most assessed from the beginning of HTA until now (e.g., contraceptives, life-sustaining technologies for critically or terminally patients, artificial organs, organ transplantation) [4]. Even though HTA application is currently wider than in the past, the majority of technologies currently assessed seem still to be the ones with the same aforementioned characteristics (e.g., genetic testing or therapy, ultrasonography for fetal sex selection, stem cell research).

The original intent of TA to be as much comprehensive as possible, was rapidly neglected towards more rapid and easier reports (e.g., "horizon scanning", "rapid HTA") or focusing only on certain sets of impacts or concerns (defined "domains" by the European network for Health Technology Assessment, and called "dimensions" in the present document). "Partial TA" has

been indeed often preferred to decision makers in circumstances where selected impacts are of particular interest or because of resource constraints [5].

1.1.2. Health Technology

Many different definitions of health technology are available in the literature. For example, health technology is defined by [6] as drugs, devices, and medical and surgical procedures used in the prevention, diagnosis, treatment, and rehabilitation of disease. It is also defined by the World Health Organization (WHO) as the "application of organized knowledge and skills in the form of devices, medicines, vaccines, procedures and systems developed to solve a health problem and improve quality of lives", comprising also organizational systems used in health care. Taxonomies of technology and its attribute have been proposed, often dividing it by discipline or by a single attribute. Health Technologies are frequently grouped in accordance to their physical nature (e.g., drugs, biologics, devices, equipment and supplies), purpose (e.g., prevention, screening, diagnosis, treatment, rehabilitation, palliation) and stage of diffusion (e.g., future, experimental, investigational, established, obsolete). However, differences within each group are not always clearly delineated and not all technologies fall neatly into single categories.

A comprehensive, even though not exhaustive, definition of technology is provided by [7] and reported in Table 1.

This thesis focuses on "common" technologies (e.g., medical devices), but it also addresses hospital services that may be considered technologies whereas they are referred to hospital policy and strategy as alternatives for strategic directions, for deciding which kind of hospital service is convenient to implement. Scientific studies stating that "hospital service" follows under the definition of "technology" within Health Technology Assessment are not available at the state-of-the-art. However, hospital services have been studied through HTA, considering it as important "health technology asset" [8].

Categories	Illustrative components (what it contains)	Dominant perspective (what it does)	Illustrative sources
A. Technology as an artifact or instrument	• ideas • instruments • machines • systems • devices • tools • products • processes • solutions	• operationality • instrumentality • functionality • enabling qualities	[9] [10] [11]
B. Technology as a process	• stage and activities ✓ research ✓ testing ✓ prototyping ✓ manufacturing ✓ commercialization ✓ experimentation ✓ development ✓ design ✓ engineering ✓ marketing ✓ transfer & exchange ✓ simulation • outcomes and outputs ✓ innovations ✓ knowledge (publications, patents)	• creates the means of developing, producing and delivering products and services • creates new realities	[12] [13] [14] [15]
C. Technology as knowledge and information	• information • intelligence • techniques • methods • procedures • approaches	• provides input to the generation, conduct & performance of economic & other activities & the means to do so	[16] [17] [18]
D. Technology as policy and strategy	• alternative for strategic direction • limitations to strategic and policy decisions	• defines, delineates, and sets boundaries to policy and strategy	[19]
E. Technology as organizational dimensions	• core competencies • competitive edge	• differentiates among organizations • provides the context for structure and processes	[20] [21]

Table 1 – Definitions of Technology: A Summary of Individual, Organizational and Socio-Economic Categories (from [7])

1.1.3. Health Technology Assessment

In addition to the lack of a standardized definition of Health Technology, also Health Technology Assessment is not rigorously defined and scientific literature, as well as international societies and associations devoted to HTA, provides different definitions of HTA. For example, [22] states that assessment of a medical technology is "any process of examining and reporting properties of a medical technology used in health care, such as safety, efficacy, feasibility, and indications for use, cost, and cost-effectiveness, as well as social, economic, and ethical consequences, whether intended or unintended"; Health Technology Assessment International (HTAi) society reports that "HTA is a field of scientific research to inform policy and clinical decision making around the introduction and diffusion of health technologies. It is a multidisciplinary field that addresses the health impacts of technology, considering its specific

healthcare context as well as available alternatives. Contextual factors addressed by HTA include economic, organizational, social, and ethical impacts. The scope and methods of HTA may be adapted to respond to the policy needs of a particular health system"; the European network for Health Technology Assessment (EUnetHTA) states that "HTA is multidisciplinary process that summarises information about the medical, social, economic and ethical issues related to the use of a health technology in a systematic, transparent, unbiased, robust manner. Its aim is to inform the formulation of safe, effective, health policies that are patient focused and seek to achieve best value. Despite its policy goals, HTA must always be firmly rooted in research and the scientific method".

It is interesting noticing that most of the definitions of HTA, such as the ones previously reported, are strongly heterogeneous and include different kind of dimensions of analysis, different characteristics, and different meanings of "health technologies". Particularly, clinical aspect is the most frequently included aspect, followed by economic aspect [23]. However, it is unclear how, in HTA bodies around the world, various criteria are taken into account in each decision [24]. On the other hand, all references seem to be in accordance to include multidisciplinary teams, and to let HTA serve to "translate" scientific findings and approach into practical and intelligible information to be used from decision makers. Hence, one of the main challenges of HTA is to provide easy-to-use tools to decision makers through scientific and rigorous methods.

Depending upon the topic and scope of the assessment, multidisciplinary teams can be composed by a broad variety of professionals (e.g., physicians, nurses, managers of healthcare institute, laboratory technicians, patients, epidemiologists, economics, lawyers, clinical/biomedical engineers). Particularly, clinical engineers play a crucial role in the assessment, since they own transversal skills enabling them to interact with all the professionals involved.

Even if there is a great variation in the scope, selection of methods and level of detail in the practice of HTA, most HTA activity involves the following steps [3]:

1. Identify assessment topics
2. Specify the assessment problem or questions
3. Retrieve available relevant evidence
4. Generate or collect new evidence (as appropriate)
5. Appraise/interpret quality of evidence
6. Integrate/synthesize evidence
7. Formulate findings and recommendations
8. Disseminate findings and recommendations

Anyhow, not all assessment programs conduct all of these steps, and they are not necessarily conducted in a linear manner [3].

Often, assessment topics are determined by the mission or purpose of an organization. Generally, technologies are assessed on a reactive basis (referring to technologies already in the market), under request of national and regional health plans, as well as other third-party payers, in order to decide whether or not adopting a particular technology. However, "horizon scanning" has been developed in order to provide prompt information about new and emerging health care interventions [25], [26], [27], [28]. Horizon scanning is presented in Paragraph 2.2.

Regarding when to conduct an assessment, there is not a "right" timing to perform HTA and, as [29] stated, "It's always too early until, unfortunately, it's suddenly too late!". In this context, one of the main issues is related to the fast development and progress of technologies: by the time a HTA is conducted, reviewed, and disseminated, its findings may be outdated.

Methods used for performing HTA can be divided into two groups: primary data methods involve collection of original data (e.g., clinical trials, observational studies); integrative methods (or secondary or synthesis methods) involve combining data or information from existing sources, including primary data studies [3]. Primary data method ranges from more scientifically rigorous approach for determining the causal effect of health technology (e.g., Randomized Controlled Trials – RCTs), to less rigorous ones, such as case series. However, methods frequently used for performing HTA are integrative methods, particularly systematic reviews and meta-analysis, based on primary data studies (e.g., journal articles, epidemiological data sets). More generally, methods used to combine or integrate data from primary sources include systematic literature review, meta-analysis, modeling (e.g., decision trees, state-transition models), group judgment, unstructured literature review, expert opinion.

Specifically, modeling is used to represent (or simulate) health care processes or decisions and their impacts under conditions of uncertainty, such as in the absence of a wide amount of data or when it is not possible to collect data on all potential conditions, decisions, and outcomes of interest. Particularly, Multi-Criteria Decision Analysis (MCDA) is raising the attention of researchers and decision makers. Indeed, MCDA methods provide greater transparency and consistency in decision-making [24].

On the other hand, several tools are available for assessing different dimensions within HTA. For example, many economic analysis methods can be found in the literature, such as cost-of-illness analysis; cost-minimization analysis; cost-effectiveness analysis (CEA), including cost-utility analysis (CUA) and cost-consequence analysis; cost-benefit analysis (CBA); budget-impact analysis (BIA).

All the topics mentioned in the present chapter, that constitute the heterogeneity of health technologies and HTA, have been widely debated in the literature, letting raise two different positions: the first one asserts that health technology can be assessed in any meaningful sense at all, conceding reports to be treated as just one account among many, incommensurable accounts [30]; the second one [31] criticized this position as tantamount to "methodological anarchy", stating a more rigorous approach was necessary. Trying to answer this challenge, proposing a structured approach taking into account, at the same time, the peculiarities of each technology to be assessed, has been one of the purposes of the present work.

Moreover, as reported by [3], some of the main barriers of HTA can be listed as follow:

- Technological imperative: in wealthy countries, there is often the expectation that new is better, and the inclination to use a technology that has potential for some benefit, however marginal or even poorly substantiated [32];
- Limited resources for HTA: resources allocated for HTA are often drastically small compared to national health care spending;
- Insufficient primary data: primary studies and other data are not always available, especially at a local or regional level, whereas peculiarities of each country is essential for assessing technologies to be adopted;
- Timing misalignment: HTA reports are often time-consuming and results of the analysis may be available too late compared to the real need;
- Marketing and promotion: provided by health care product companies with the unique purpose of selling, they can weight against HTA findings;
- Political actions: they can circumvent HTA, through "lobbying" or "pressure groups". This occur, for example, when political (regional, national or international) directives or programs push and press healthcare institutions as well as citizen to adopt certain technologies, in contrast to findings based on available evidences, or in the absence of rigorous evidences;
- Implementation barriers: there are several barriers to implementing HTA, such as complex and technical formats of HTA reports, absence of real-world applications, and narrow focus [33]. Moreover, HTA recommendations may be difficult to implement due to clinicians' and other providers' reluctance to change long-standing practice routines. Furthermore, lack of versatility of many HTA reports does not allow to implement solutions in certain cases due to practical external constraints, such as particular environment, professional training, or other resources that are unavailable in a particular facility.

In recent years, a new approach of HTA, called “rapid HTA” is emerging due to decision makers increasing requests for faster responses. Compared to full HTAs, rapid HTAs have limiting scope to fewer types of impact, focus searches on fewer bibliographic databases, rely on fewer types of studies, use shorter and more qualitative syntheses with categorization of results without meta-analysis [34].

Another interesting trend is the decentralization of HTA. Indeed, despite the initial approach of conducing HTA by government agencies and other national- or regional-level organization, HTA evolved into a more decentralized function [35], [36], taking into account peculiarities of each specific context, and considering different perspectives.

1.2. MCDA

The use of Multi-Criteria Decision Analysis (MCDA) in health care context represents one of the most frequently used decision-making frameworks [37] [38], providing a sound and rigorous approach for decision making in health care [39]. Indeed, MCDA is widening used in the healthcare context with a statistically significant and steady increase over the years as reported by [40] (Figure 1).

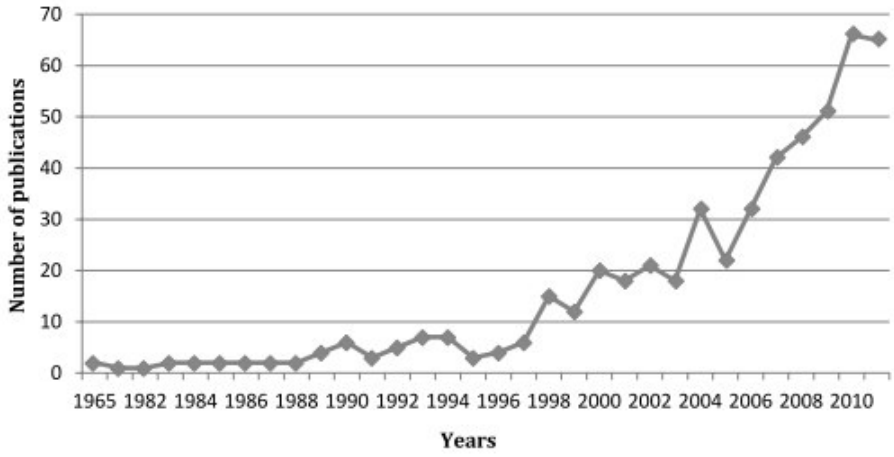

Figure 1 – Publication pattern of MCDA applications in health over the years 1960-2011 (from [40])

MCDA can be described as a tool based on a set of qualitative and quantitative data that simultaneously take into account multiple and often conflicting factors [41]. It can be defined as "a set of methods and approaches to aid decision-makers, where decisions are based on more than one criterion, which make explicit the impact on the decision of all the criteria applied and the relative importance attached to them" [24]. Some types of MCDAs are based on sophisticated algorithms to suggest optimal choice, while others just aid to provide some structure to the deliberative process. It is important underlying that MCDA represents only a support to decision making, requiring anyway degrees of judgment by decision makers.

In the previous paragraphs, the importance of including different dimensions (and, consequently, criteria) for assessing a technology was underlined. MCDA allows to involve multiple criteria and multiple stakeholders, through a systematic process that clarifies what is being taken into account (the "criteria"), how each of those criteria is to be measured, and how much importance ("weight") to put on each from decision makers perspectives.

A wide range of MCDA tools are available in the literature, used in different contexts (e.g., business, management, healthcare). Some of Multi-Criteria Decision Making (MCDM) methods, many of which implemented by specialized decision-making software, include: Aggregated Indices Randomization Method (AIRM); Analytic Hierarchy Process (AHP); Analytic Network Process (ANP); Data Envelopment Analysis (DEA); Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH); Multi-Attribute Utility Theory (MAUT); Multi-Attribute Value Theory (MAVT); Nonstructural Fuzzy Decision Support System (NSFDSS); Potentially All Pairwise RanKings of all possible Alternatives (PAPRIKA); PROMETHEE (Outranking); Simple Multi-Attribute Rating Technique (SMART) [42].

A brief description of some MCDMs and related software is provided by [43] and reported in Table 2.

Program/Developer/Price	**Description**
1000Minds (1000Minds Ltd.) Free for academic purpose, other negotiable	Helps with decision-making, prioritization and discovering stakeholder preferences. Depending on application, can also help in considering alternatives and allocation of budget or other scarce resources. As well as stand-alone decision tools, offers customizable processes to include potentially up to 1000s of participants in a variety of group decision-making activities. Applies patented PAPRIKA (Potentially All Pairwise RanKings of all possible Alternatives) method. Web-based software with a tab-based interface. Preferences with numerous pairwise questions on criteria. Various ways to analyze results. Sharing results on the net and possibility for voting or surveys.
Analytica (Lumina Decision System, Inc.) Professional version $995	Helps in building business models or policy analysis. Has intuitive influence diagrams for creating models and allows communicating clearly with colleagues and clients. Its Intelligent Arrays allows creating and managing multidimensional tables with an ease and reliability and efficient Monte Carlo allows quickly evaluating risk and uncertainty and finding out what variables really matter and why. Object-oriented visual interface, with which one can implement practically any method. Various graph-building. Pre-defined modules available, for example, for MAUT, optimization, and risk analysis. Various distributions available.
Criterium Decision Plus 3.0 (InfoHarvest) $895	Can be used for managing the entire decision process. Applying a structured methodology to decision making helps in making precise, thoughtful and completely supportable decisions. Includes Direct Tradeoffs, larger models, powerful graphics and extensive options for supporting insightful, persuasive decision making faster and for more complex models than ever. Basic MAVT software with AHP functionality
Decide IT (Preference) Free for academic use. Commercial license: $1900 + $900/year	Enables to carry out reliable risk and decision analyses. Includes state-of-the-art decision methodologies and mathematical analysis in an efficient and user friendly software. Comes with an easy-to-use graphical user interface in which decision trees together with criteria hierarchies constitute the main schematic overview of the decision architecture. Such models are very useful in cases of complex decisions, as they provide the decision maker and decision analyst with a graphical presentation of the decision situation and show the internal relations between options, objectives and uncertain parameters. MCDA

Program/Developer/Price	Description
	software providing both value and decision tree approaches. Uses intervals and inequality relations in weighting. Probabilistic analysis of imprecise results
Decision Tools (Palisade Corporation) Depends on the license (Stand-alone single-user license: £2000)	Integrated set of programs for risk analysis and decision making under uncertainty that runs in Microsoft Excel. Includes @RISK for Monte Carlo simulation, PrecisionTree for Decision Trees, and TopRank for "What-If" sensitivity analysis. In addition, comes with StatTools for statistical analysis and forecasting, NeuralTools for predictive neural networks and Evolver and RISKOptimizer for optimization. All programs integrate completely with Microsoft Excel for ease of use and maximum flexibility
GMAA (Universidad Politécnica de Madrid) Available free of charge for academic purpose	DSS based on an additive multi-attribute utility model that accounts for incomplete information concerning the inputs. The system is intended to allay many of the operational difficulties involved in the DA cycle, which can be divided into four steps: structuring the problems; identifying the feasible alternatives, their impact and uncertainty; quantifying preferences; evaluating strategies and performing Sensitivity Analysis. MAUT software with a possibility to use intervals to model imprecision
Logical Decisions (Logical Decisions) 1 installation: $895	Allows evaluating choices by considering many variables at once, separating facts from value judgments and explaining choices to others. Uses techniques from the field of decision analysis to help in making more effective decisions. Provides a variety of methods for assessing attribute weights and has many results displays. Basic MAVT software with AHP functionality
M-MACBETH (Bana Consulting Lda) Free demo available, academic license $175, professional $1750	Uses interactive approach that requires only qualitative judgments about differences to help a decision maker or a decision-advising group quantify the relative attractiveness of options. Employs an initial, interactive, questioning procedure for comparing two elements at a time, requesting only a qualitative preference judgment. As judgments are entered into program, it automatically verifies their consistency. A numerical scale is generated that is entirely consistent with all the decision maker's judgments. Through a similar process weights are generated for criteria. MAVT software that support Macbeth method, various graphical ways to assess the parameters
TESLA (Quintessa)	Software tool for supporting decision makers when faced with complex decision problems. Provides a means to break a decision down into a hierarchical structure, simplifying the problem and presenting it in such a way that information can be easily gathered and categorized. Software with decision tree approach and evidence based updating of probabilities
V.I.S.A. Decisions (SIMUL8 Corporation Ltd) Standard version (Includes standalone application and web-based version) $495	Created for decisions with multiple, tough to balance factors; where no option matches all of the criteria perfectly; or for decisions where more than one person has a say in how the decision is made. It allows weighing up all the factors using a considered and sound process and documents how decision was made and why it was the right outcome for future reference. Basic MAVT software

Table 2 – Description of some Multi-Criteria Decision Methods, related software and other information (from [43])

The comparative analysis of multi-criteria decision support system published by [43], reported also the classification of the 10 different tools presented in Table 2, considering

different features characterizing each system. 1000Minds, DecideIT, and GMAA results to be free of charge for academic purposes. Even though 1000Minds was rated at the 5th position, it is the only one that runs on web browser and not on proprietary platform (Windows), and it is the easiest to use among the others, requiring low level of expertise. These characteristics are very important for decision makers because they often do not possess technical skills, needing user-friendly tools, and they are frequently subjected to economic constraints.
For these reasons, PAPRIKA tool will be described in detail.

1.2.1. PAPRIKA

PAPRIKA is a method developed in 2008 by [44]. It specifically addresses additive multi-attribute value models with performance categories ("value models"), where each criterion is demarcated into mutually exclusive categories. In the most traditional approaches, value score of each criterion is assigned using either identical rating scales (e.g., 1-100) or single-criterion value functions; normalized criterion weights are used to represent the relative importance of the criteria. Most of the available tools provide a ratio or interval scale measurements of decision-makers' preferences. PAPRIKA is based on the same principle of weighting criteria, but it implements a different method, without interval scale measurements provided to decision-makers, but ranking potentially all hypothetically possible alternatives in a pool that changes over time. Particularly, PAPRIKA let decision-maker pairwise rank potentially all "undominated pairs"[1] of all possible alternatives represented by the value model being scored. Conversely, the alternatives in "dominated pair" are inherently pairwise ranked. The number of undominated pairs to be explicitly ranked is minimized by PAPRIKA through identification and elimination of all pairs implicitly ranked, via the transitivity property of additive value models: having called "degree" the number of criteria included in the study, the algorithm starts comparing alternatives at 2nd-degree (pairwise comparisons of two alternatives, considering 2 criteria each) up to the highest degree (i.e., total number of criteria included in the study). For example, ranked 2nd-degree pairs implies ranking of some of 3rd-degree pairs, etc. From the inequalities (decision maker prefers one alternative among two during pairwise comparisons) or equalities (decision maker doesn't express a preference, stating both the alternatives are equal), point values are obtained via linear programming. Hence, PAPRIKA automatically avoids potential inconsistencies in the decision-maker's rankings as well as redundancies. The flowchart of the PAPRIKA method is presented in Figure 2.

[1] "Undominated pair" is a pair of alternatives where one is characterized by a higher ranked category for at least one criterion and a lower category for at least one other criterion than the other alternative.

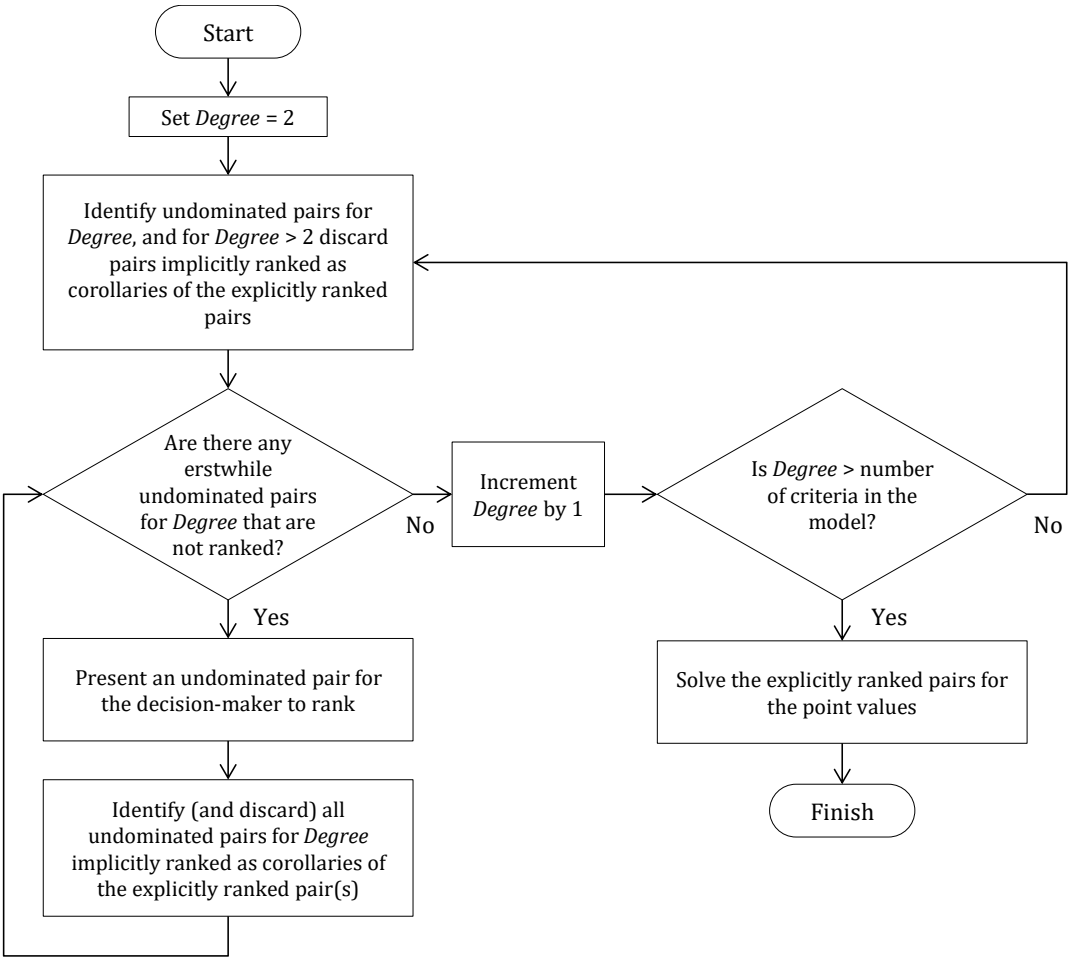

Figure 2 – Flow chart of the PAPRIKA method (from [44])

The method proposed by PAPRIKA implies two computationally processes for (1) identifying all unique undominated pairs, and (2) identifying all implicitly ranked pairs.

The number of undominated pairs (N) and the number of unique undominated pairs (U) of degree z ($z = 2, 3, \dots, n$) are given by the Equation 1 and Equation 2 respectively.

Equation 1

$$N(n, y, z) = {}^{n}C_{z}(2^{z-1} - 1)({}^{y}C_{2})^{z}y^{n-z}$$

Equation 2

$$U(n, y, z) = {}^{n}C_{z}(2^{z-1} - 1)({}^{y}C_{2})^{z}$$

where ${}^{n}C_{z}$ is the number of combinations of the n criteria taken z at-a-time, and ${}^{y}C_{2}$ is the number of combinations of the y categories for each criterion taken two at-a-time.

After a given pair has been ranked by decision-makers, implicitly ranked pairs are identified, proposing hypothetical ranking to decision makers, until they are explicitly ranked by decision makers (for more details, see [44]).

The number of pairwise comparisons to be answered by decision makers depends by their answers and preferences, that are linked to the ability of the algorithm to rank all undominated pairwise comparisons.

PAPRIKA method results to be easy-to-use and more natural from decision makers' perspective, compared to the traditional methods (e.g., SMART) [44]. Moreover, the real-world application suggested that decision makers are able to rank comfortably more than 50 and up to at least 100 pairs, and in a short period.

Hence, this method resulted to be the most appropriate for the aims of the present work, in order to combine scientific approach with real practical needs of decision makers.

Chapter 2
Medical devices assessment

In Europe, the number of medical technologies patented each year has doubled the number of drugs and biotechnologies. In 2014, medical technologies were 1st for IP applications. This suggests that in the next years, thousands of new medical devices will be available to be introduced into the market, causing a significant shift in healthcare costs from drugs to devices.

Today, the unique technologies assessed through standardized methods and tools are drugs and patient-oriented procedures. Indeed, several methods have been developed in the past for drugs, which are deeply different from medical devices or other technologies. Indeed, differently from drugs, medical devices require significant maintenance or installation costs; price is more dynamic; medical device efficacy is user dependent, since outcomes often depend on training and experience of the operator (e.g., the skill of surgeons using minimally invasive surgery can make the difference) [45]. Last, but even more important, medical devices can be prognostic, therapeutic, diagnostic or for rehabilitation purposes, while drugs are only therapeutic. The adopted methodological frameworks for HTA currently available do not fully encounter the challenges rising from technologies as medical devices [46], causing the necessity to adapt the tool to each technology.

In this chapter two different medical devices are assessed, through two different case studies: the first research study concerns the identification of the best medical device for thyroidectomy and it was performed through a more typical HTA approach based on systematic review of the available literature, considering the most important dimensions for a comprehensive assessment; the second one [47], [48] represents a preliminary study for

assessing an innovative technology not yet in the market. Particularly, the main contribution given in the latter was the identification of the major needs at the state-of-the-art, of the available solutions, of the most important features to be developed for the innovative technology, that were summarized into the overall preliminary assessment.

2.1 Hospital-Based HTA of vessel sealing in thyroidectomy

As briefly introduced in the first chapter, the assessment of technologies already in the market often differs from technologies not yet in the market. Indeed, for the first kind of technologies, more data are usually available in the literature and comparison of the different dimensions (e.g., clinical effects) among different technologies results to be easier. This paragraph takes into account the more traditional HTA approach, as presented in the first chapter, performed on a medical device used for surgical operations.

Particularly, the study aimed to assess the traditional hemostatic technique (i.e., classic suture ligation) and vessel sealing systems (i.e., disposable bipolar vessel sealer LigaSure, reusable bipolar vessel sealer BiClamp, and disposable ultrasonic coagulating shear Harmonic Focus) in thyroidectomy, in order to identify the best technology to be used in an hospital that served as case study ("G. Pascale" hospital in Naples, Italy). Hospital-Based Health Technology Assessment was conducted in order to identify an effective, appropriate and economically sustainable technology as alternative to traditional hemostatic technique in thyroidectomy, at the G. Pascale hospital, where currently an average of 100 total thyroidectomies are performed each year, using the standard technique.

2.1.1 Introduction

After the introduction by Kocher and Billroth of a surgical technique (1872) that reduced mortality from 75% to 0.5%, the thyroidectomy has become one of the most frequently used surgical procedures in endocrinal surgery [49]. The majority of pathologies related to thyroid, especially in case of neoplasia, are treated through a total thyroidectomy, in order to ensure the removal of the whole site and prevent possible relapses.

In thyroidectomy, as well as in other kind of surgical procedures, hemostasis is considered crucial, and the possible consequences of intra-surgeries bleeding (e.g., hematomas, infections) have to be reduced and prevented.

The traditional hemostatic technique for achieving hemostasis during a surgical procedure consists of closing vessels through tie ligation. The mechanism associated with this technique is vessels occlusion through natural coagulation and aggregation of fibrin. Even though this method is still in use, nowadays other new methods are usually preferred.

Indeed, in the last decades, besides mechanical hemostatic techniques (e.g., sutures, clips), technologies based on coagulation techniques, using radiofrequencies ("RF") or ultrasound

energy, have been developed. These methods allow managing both dissection and hemostasis during surgical procedures.

Particularly, the vessel sealing is a hemostatic technique performed by a medical device in which collagen and elastin of vessel wall are fused and a permanent seal is formed.

2.1.2 Methods

2.1.2.1 Analyzed medical devices

Medical devices available on the market were firstly identified. Specifically, medical devices for vessel sealing currently in use can be divided into disposable and reusable. Within the first category, we included the "ForceTriad™ radiofrequency energy platform + LigaSure™ Small Jaw disposable handpiece" from Covidien LLC (called "DRF" as Disposable RF system in the present study) and the "Generator GEN11 + Ultrasonic shear Harmonic Focus® from Ethicon Endo Surgery LLC (called "US" as Ultrasound system in the present study). Regarding the reusable devices, we included the "VIO 300D radiofrequency generator + BiClamp® reusable handpiece" from Erbe Elektromedizin, GmbH (called "RRF" as Reusable RF system in the present study). We excluded the hybrid system "Thunderbeat" from Olympus Medical System Systems Corp, and "AF Maxium radiofrequency generator + MarClump Cut IQ instrument" from Gebruder Martin Gmbh &Co. Kg, "ARC radiofrequency generator + TissueSeal Plus instrument" from Bowa-Electronic Gmbh & Co. Kg, and "SonoSurg ultrasonic generator + dedicated reusable instruments" from Olympus Medical System Systems Corp, since no clinical studies of their use in thyroidectomy are available in the literature. Particularly, regarding the above mentioned techniques included in the study, the handpiece of DRF system, i.e., disposable hand-held dissector based on radiofrequency energies, integrates cutting mechanism and it is designed for the use in open procedures. The handpiece of ultrasound system, hand-held ultrasonic dissector in titanium, provides also cutting mechanisms. The handpiece of RRF system delivers radiofrequency current and the hand-held BiClamp 150C is specifically designed for the use in open procedures in thyroidectomy. It doesn't provide cutting mechanisms.

Before performing the technology assessment, we defined our research question through P.I.C.O. (Population, Intervention, Comparison, Outcomes) method identifying for each dimension the following:

- Population: Patients under total thyroidectomy surgical operation;
- Intervention: ultrasonic/radiofrequency, disposable/reusable vessel sealing systems in thyroidectomy;

- Comparison: traditional hemostatic technique VS vessel sealing systems;
- Outcomes: reduction of surgery duration, hospital stay, intra-operative bleeding, incidence of post-operative complications (indicators generally used for assessing the effectiveness by the literature) and costs.

Hence, the research question is: "Can the use of vessel sealing systems in thyroidectomy reduce the abovementioned outcomes compared to the traditional hemostatic technique?"

2.1.2.2 Data

We conducted a systematic review of the literature, including electronic databases (Pubmed and Cochrane Library) as well as gray literature, thesis and medical devices manufacturer reports.

For searching into electronic databases, we used a combination of keywords related to thyroidectomy and the three aforementioned technologies, as follow:

- *("thyroidectomy"[MeSH Terms] OR "thyroidectomy"[All Fields]) AND sealing[All Fields]*, that resulted in 61 papers (including 18 clinical trials and 36 comparative papers) in PubMed database, and 29 papers (including 24 clinical trials) in Cochrane Library;
- *(LigaSure[All Fields] AND ("thyroidectomy"[MeSH Terms] OR "thyroidectomy"[All Fields]))*, that resulted in 65 papers (including 20 clinical trials and 29 comparative papers) in PubMed database, and 27 (including 22 clinical trial) in Cochrane Library;
- *(BiClamp[All Fields] AND ("thyroidectomy"[MeSH Terms] OR "thyroidectomy"[All Fields]))*, that resulted in 3 papers in PubMed database, and no results in Cochrane Library;
- *(Harmonic Focus[All Fields] AND ("thyroidectomy"[MeSH Terms] OR "thyroidectomy"[All Fields]))*, that resulted in 29 papers (including 13 clinical trials and 13 comparative papers) in PubMed database, and 18 (including 17 clinical trials) in Cochrane Library.

Moreover, other sources (i.e., systematic reviews and meta-analysis) were considered and studied.

A total of 55 different papers was selected and included in our study (Table 3), after having applied the following criteria (with no date of publication restrictions):

- Studies conducted on humans (studies involving animals were excluded);
- Papers in English and Italian languages;

- Trials using at least one of the following hemostatic techniques: traditional hemostatic technique, ultrasonic or radiofrequency, disposable or reusable vessel sealing systems.

Authors	Date of publication	Instrument	Control	Number of patients	Type of thyroidectomy	Design of the study
Oussoultzoglou et al. [50]	2008	RF reusable	RF disposable	46 vs 40	Total	No RCT
Pniak et al. [51]	2014	RF reusable	Standard method	679 vs 263	Total and partial	No RCT
Manouras et al. [52]	2005	RF disposable	Standard method	94 vs 90	Total	RCT
Manouras et al. [53]	2008	RF disposable vs Ultrasuoni	Standard method	148 vs 144 vs 90	Total	No RCT
Teksoz et al. [54]	2013	RF disposable	Ultrasound	126 vs 119	Total	RCT
Chang et al. [55]	2011	RF disposable + Ultrasound	Standard method	1163 vs 722	Total	No RCT
Shen et al. [56]	2005	RF disposable	Standard method	89 vs 62	Total and partial	No RCT
Youssef et al. [57]	2008	RF disposable	Standard method	15 vs 15	Total and partial	No RCT
Lepner et al. [58]	2007	RF disposable	Standard method	204 vs 199	Total and partial	No RCT
Petrakis et al. [59]	2004	RF disposable	Standard method	270 vs 247	Total	No RCT
Lachanas et al. [60]	2005	RF disposable		72	Total	No RCT
Cordòn et al. [61]	2005	Ultrasound	Standard method	7 vs 12	Total and partial	RCT
Ortega et al. [62]	2004	Ultrasound	Standard method	57 vs 57	Total and partial	RCT
Sista et al. [63]	2012	Ultrasound	Standard method	119 vs 122	Total and partial	RCT

Authors	Date of publication	Instrument	Control	Number of patients	Type of thyroidectomy	Design of the study
Calò et al. [64]	2012	Ultrasound	Standard method	681 vs 470	Total	No RCT
Gentileschi et al. [65]	2011	Ultrasound	Standard method	43 vs 38	Total	RCT
Kiriakopoulos et al. [66]	2004	RF disposable	Standard method	40 vs 40	Total and nearly total	No RCT
Materazzi et al. [67]	2013	Ultrasound	Standard method	141 vs 127	Total	RCT
Alesina et al. [68]	2010	RF reusable	Standard method	61 vs 62	Total and partial	No RCT
Cipolla et al. [69]	2008	RF disposable	Standard method	53 vs 52	Total	No RCT
Parmeggiani et al. [70]	2005	RF disposable	Standard method	70 vs 120	Total	RCT
Glover et al. [71]	2014	RF disposable		399	Total	No RCT
Ruggiero et al. [72]	2014	Ultrasound	RF disposable	200 vs 200	Total	RCT
Kuboki et al. [73]	2013	RF disposable	Standard method	14-15	Total and partial	No RCT
Saint Marc et al. [74]	2007	RF disposable	Standard method	100 vs 100	Total	RCT
Mourad et al. [75]	2011	Ultrasound	Standard method	34 vs 34	Total	RCT
Kwak et al. [76]	2014	Ultrasound	RF disposable	130 vs 116	Total and partial	RCT
Markogiannakis et al. [77]	2011	Ultrasound		45	Total	RCT
Hahn et al. [78]	2015	Ultrasound	Standard method	82 vs 76	Total and partial	No RCT
Pelizzo et al. [79]	2014	Ultrasound	Standard method	139 vs 147	Total	No RCT
Pardal [80]	2011	Ultrasound	Standard method + RF disposable	419 vs 468	Total	No RCT

Authors	Date of publication	Instrument	Control	Number of patients	Type of thyroidectomy	Design of the study
Bove et al. [81]	2012	Ultrasound vs RF disposable	Standard method	80 vs 80 vs 80	Total	No RCT
He et al. [82]	2011	Ultrasound	Standard method	91 vs 54	Total	RCT
Duan et al. [83]	2013	Ultrasound	Standard method	389 vs 389	Total	RCT
Molnar et al. [84]	2014	RF disposable	Standard method	10 vs 10	Total	No RCT
Cannizzaro et al. [85]	2014	Ultrasound	Standard method	141 vs 124	Total	RCT
Kirdak et al. [86]	2005	RF disposable	Standard method	8 vs 9	Total and partial	No RCT
Barbaros et al. [87]	2006	RF disposable	Standard method	50 vs 50	Total and nearly total	No RCT
Coiro et al. [88]	2015	RF disposable	Standard method	95 vs 95	Total	RCT
Zarebczan et al. [89]	2011	RF disposable	Ultrasound	87 vs 36	Total and partial	No RCT
Sartori et al. [90]	2008	RF disposable vs Ultrasound	Standard method	50 vs 50 vs 50	Total	RCT
Di Renzo et al. [91]	2010	RF disposable vs Ultrasound	Standard method	31 vs 31 vs 31	Total	RCT
Konturek et al. [92]	2012	Ultrasound	Standard method	41 vs 41	Total	RCT
Hwang et al. [93]	2014	RF disposable	Ultrasound	64 vs 62	Total	RCT
Docimo et al. [94]	2012	Ultrasound	Standard method	100 vs 100	Total	RCT
Papavramidis et al. [95]	2010	Ultrasound	Standard method	45 vs 45	Total	RCT
Marrazzo et al. [96]	2007	RF disposable	Standard method	25 vs 25	Total	RCT

Authors	Date of publication	Instrument	Control	Number of patients	Type of thyroidectomy	Design of the study
Lombardi et al. [97]	2008	Ultrasound	Standard method	100 vs 100	Total	RCT
Frazzetta et al. [98]	2005	Ultrasound	Standard method	60 vs 60	Total	RCT
Ferri et al. [99]	2011	Ultrasound	Standard method	50 vs 50	Total	RCT
McNally et al. [100]	2009	RF disposable	Ultrasound	59 vs 15	Total	No RCT
Miccoli et al. [101]	2010	Ultrasound	Standard method	31 vs 31	Total	RCT
Pons et al. [102]	2009	Ultrasound vs RF disposable	Standard method	20 vs 20 vs 20	Total	RCT
Hallgrimsson et al. [103]	2008	Ultrasound	Standard method	27 vs 24	Total	RCT
Prgomet et al. [104]	2009	Ultrasound	Standard method	125 vs 37	Total and partial	No RCT

Table 3 - List of publications selected and included in the HTA of vessel sealing in thyroidectomy. RCT stands for Randomized Controlled Trial

2.1.2.3 Clinical effectiveness

The criteria considered for assessing clinical effectiveness, as already introduced, are:

1. Reduction of surgery duration;
2. Reduction of hospital stay;
3. Reduction of intra-operative bleeding;
4. Reduction of incidence of post-operative complications (laryngeal nerves injuries and cases of hypocalcaemia).

The first three indicators were calculated as weighed average within the included clinical trials, based on the number of subjects in the studies. The fourth indicator was calculated considering the incidence of total number of laryngeal nerves injuries and cases of hypocalcemia within the total examined population.

2.1.2.4 Economic Analysis

Among the 55 studies selected for the effectiveness analysis, 12 papers focused on cost-to-cost economic analysis (Chang et al. [55], Ortega et al. [62], Kiriakopoulos et al. [66], Alesina et al. [68], Cipolla et al. [69], Parmeggiani et al. [70], Saint Marc et al. [74], Konturek et al. [92], Lombardi et al. [97], Frazzetta et al. [98], Pons et al. [102], Hallgrimsson et al. [103]), with contrasting results.

In order to assess the economic dimension, break-even point (BEP) analysis was performed. Particularly, costs are detailed in the following subsections, and there were divided into fixed costs (i.e., purchasing, maintenance, and installation) and variable costs (i.e., consumables, surgical team and operating room, hospital stay, and sterilization). Revenues were calculated considering the Unit Revenue of 3,340 €, as foreseen by the Diagnosis-Related Group (DRG) 290 in the Italian Healthcare System.

The break-even points (x, in terms of number of surgeries) and the contribution margins (CM) were calculated as:

$$x = \frac{Total\ Fixed\ Cost}{Unit\ Revenue - Unit\ Variable\ Cost};\ CM = Unit\ Revenue - Unit\ Variable\ Cost$$

The break-even revenue (BER) was found by multiplying the number of surgeries corresponding to the break-even points and the Unit Revenue.

The margin of safety (MS) was calculated as:

$$MS(\%) = \frac{Expected\ revenue - BER}{Expected\ revenue} * 100$$

All the specific information on costs, presented in this work, was collected through interviews to medical devices manufacturers and contracts at the "G. Pascale" hospital. Hence, the cost analysis gathered both the literature and the specific constraints of the hospital and Italian regulations.

Purchasing costs

In Italy, the ForceTriad, VIO300D, and GEN11 generators are sold at an average value of 41,358 €, 25,620 €, and 32,940 € respectively (including taxes). In accordance to the Italian

Legislative Decree n.118 (June, 23rd 2011), the cost is amortized over 5 years. Hence, the depreciation is of 8,271.6 € for the ForceTriad, 5,124 € for the VIO 300D, and 6,588 € for the GEN11.

Maintenance costs

Considering the annual cost for medical electrical equipment maintenance approximately equal to the 10% of purchasing costs within a full-risk maintenance contract, we can estimate 4,135.8 € for the ForceTriad, 2,562 € for the VIO 300D, and 3,294 € for the GEN11, within the maintenance costs.

Installation costs

Generators need just to be plugged, hence there are no costs related to installation.

Therefore, the total amount of the fixed costs (sum of costs related to purchasing, maintenance and installation costs) of DRF, RRF and ultrasound systems, summarized as in Table 4, can be estimated as 12,407.4 €, 7,686.0 €, and 9,882.0 € respectively.

	Purchasing cost *(amortization 5 years)* [€]	Maintenance cost [€]	Installation cost [€]	**Total [€]**
RF disposable	8,271.6	4,135.8	0	**12,407.4**
RF reusable	5,124.0	2,562.0	0	**7,686.0**
Ultrasounds	6,588.0	3,294.0	0	**9,882.0**

Table 4 – Total amount of the fixed costs (estimation) of DRF, RRF and ultrasounds systems

Consumables

In traditional hemostatic technique, approximately 10 silk cocoons for ligation of vessels are used. Each silk cocoon costs approximately 2 € (including taxes). So, the cost amount of consumables for each operation is 20 €.

Concerning the vessel sealing systems, the major costs are related to the handpiece itself: the hand-held disposable radiofrequency dissector is sold at 483.8 € (including taxes), the hand-held reusable radiofrequency dissector, which is guaranteed for 50 operations, is sold at 1,525 € (30.5 € per operation, including taxes), the hand-held disposable ultrasounds dissector is sold at 622.2 € (including taxes).

Operating team and operating room

At the National Cancer Center G. Pascale, the thyroidectomy interventions involve 2 surgeons, 1 anesthetist, and 1 instrumentalist. Their costs per minute can be estimated as 1.67 €, 1.67 €, and 0.30 € respectively [98].

The cost of the operating room is 4.30 € per minute, including utilities, cleaning and laundry [98].

Hospital stay

The average cost of one-day stay in the hospital is 710 €, as stated by the regional report of the Regional Agency for Health and Social Care.

Sterilization costs

Sterilization process is needed only for reusable handpieces. The related cost associated to a single procedure is 1.20 €, as reported by medical devices manufacturers enrolled at the National Cancer Center G. Pascale.

2.1.3 Results

Clinical effectiveness

The three outcomes (reduction of surgery duration, reduction of hospital stay, reduction of intra-operative bleeding), presented in Table 5, were calculated as weighed average within the included clinical trials considering the number of subjects in the studies.

1. Surgery duration

Hemostatic technique	Average surgery duration [mins]	Confidence interval 95%	Number of studies	Population
Standard method	94.13	[94.10, 94.16]	40	3616
RF disposable	81.35	[81.33, 81.37]	28	2230
RF reusable	91.43	[91.36, 91.5]	3	786
Ultrasounds	70.31	[70.29, 70.33]	30	3566

2. Hospital stay

Hemostatic technique	Average hospital stay [days]	Confidence interval 95%	Number of studies	Population
Standard method	2.69	[2.65, 2.73]	21	1998
RF disposable	2.18	[2.13, 2.23]	15	1441
RF reusable	3	[2.71, 3.29]	1	46
Ultrasounds	2.8	[2.76, 2.84]	22	2566

3. Intra-operative bleeding

Hemostatic technique	Average bleeding [ml]	Confidence interval 95%	Number of studies	Population
Standard method	42.97	[42.89, 43.05]	7	557
RF disposable	31.54	[31.46, 31.62]	6	639
RF reusable	N.A.	N.A.	N.A.	N.A.
Ultrasounds	31.46	[31.33, 31.59]	4	220

Table 5 - Surgery duration, hospital stay and intra-operative bleeding calculated as weighed average within the included clinical trials, considering the number of subjects in each study

The two outcomes related to reduction of incidence of post-operative complications, presented in Table 6, were calculated considering the total number of laryngeal nerves and parotid glands injuries among the total examined population.

4. Incidence of post-operative complications

Hemostatic technique	Incidence of laryngeal nerves injuries [%]	Number of studies	Population
Conventional	2.28	32	3521
RF disposable	2.52	23	2183
RF reusable	N.A.	1	46
Ultrasounds	1.64	28	3162
Hemostatic technique	Incidence of cases of hypocalcemia [%]	Number of studies	Population
Conventional	13.55	32	3687
RF disposable	9.84	21	2089
RF reusable	6.5	1	46
Ultrasounds	10.66	30	3376

Table 6 - Incidence of post-operative complication calculated considering the total number of laryngeal nerves and parotid glands injuries among the total examined population

Economic Analysis

The average of surgery duration (Table 5) and the variable costs (detailed in the "Methods" section) were used to estimate costs of operating team and operating room for each surgery, while the average of hospital stay was used to estimate costs of hospital stay for each surgery.

Particularly, the cost related to the operating team results to be 499.8 € for the traditional haemostatic technique; 431.9 € for DRF; 483.49 € for RRF; 373.3 € for ultrasounds techniques. The cost related to the operating room results to be 404.7 € for the traditional haemostatic technique; 349.8 € for DRF; 393.1 € for RRF; 302.3 € for ultrasounds techniques. Finally, the cost related to hospital stay results to be 1,909.9 € for the traditional haemostatic technique; 1,547.8 € for DRF; 2,130.0 € for RRF; 1,988.0 € for ultrasounds techniques.

The total amount of the variable costs (sum of costs related to consumables, operating team, operating room, hospital stay and sterilization per surgery) was then estimated to be 2,834.5 € for the traditional haemostatic technique, 2,913.4 € for DRF, 3,040.3 € for RRF and 3,285.9 € for ultrasounds techniques. The total amount of the variable costs is presented in Table 7.

	Consumables [€]	Operating room [€]	Operating team [€]	Hospital stay [€]	Sterilization [€]	**Total** [€]
Conventional	20	404.76	499.83	1,909.9	0	**2,834.5**
RF disposable	583.81	349.81	431.97	1,547.8	0	**2,913.4**
RF reusable	30.5	393.15	485.49	2,130.0	1.2	**3,040.3**
Ultrasounds	622.2	302.33	373.35	1,988.0	0	**3,285.9**

Table 7 – Total amount of the variable costs (estimation, per surgery) in the use of conventional technique, DRF, RRF and ultrasounds systems

The break-even point analysis was performed only on the vessel sealing systems, since the conventional technique is unequivocally the most convenient in terms of costs, and through this technique the operating profit is reached right at the first surgery.

Figure 3 shows the results of the BEP analysis for the three different techniques.

Moreover, contribution margins resulted to be 426.61 €, 299.66 € and 54.12 € for RF disposable, RF reusable and Ultrasounds techniques respectively.

Consequently, the break-even revenue (BER) is equal to 97,127.2€ for the disposable RF, 85,671€ for the reusable RF, and 609,850.6 € for the ultrasounds technologies.

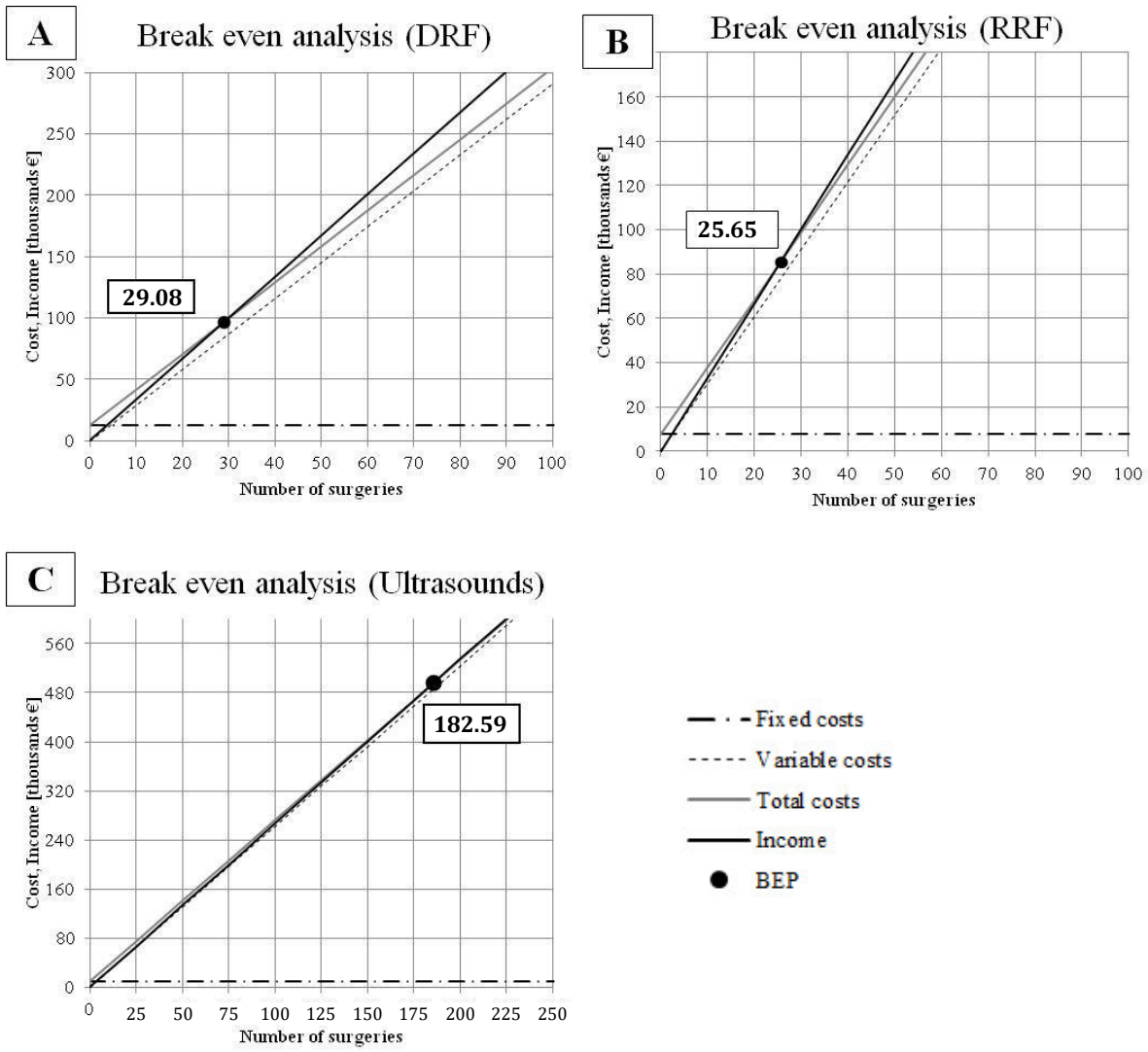

Figure 3 - Break even analysis results: disposable radiofrequency system (A), reusable radiofrequency system (B), ultrasound system (C). The number of surgeries is represented on the x-axis; the cost and income are represented on the y-axis.

As conclusion of the break-even point analysis, the margin of safety was calculated in order to understand how many surgeries can fall before the break-even point is reached for each technology.

At the G. Pascale hospital, an average of 100 total thyroidectomies is performed each year, using the standard technique.

Since the use of RRF technique allows to save an average of 2.7 minutes each surgery compared to the standard technique (Table 5), three more thyroidectomies per year may be performed through this technique, compared to the traditional one. Consequently, the expected revenue can be calculated by multiplying the expected number of surgeries (103) and the DRG290 (3,340€), resulting to be 344,020 €.

Similarly, through DRF and ultrasounds techniques, 13 and 24 minutes respectively can be saved for each surgery, allowing to perform 16 and 33 more surgeries per1 year. Thus, the expected revenues result to be 387,440 € using the DRF technique and 444,220 € using the ultrasounds technique.

Thus, the margins of safety for the three techniques result to be 74.93%, 75.1%, and -37.28% for the DRF, RRF, and US respectively.

Hence, the break-even point analysis shows that at the National Cancer Center G. Pascale at least 74.93% (using RF disposable) and 75.1% (using RF reusable) of total thyroidectomies must be guaranteed for not causing economic loss. Conversely, the ultrasounds technique is not economically sustainable for this hospital.

The operating incomes per year, calculated as the difference between total incomes and total costs, result to be 37,079.36 € considering 116 surgeries with DRF technique, 23,178.98 € considering 103 surgeries for the RRF technique, and loss equal to 2,684.04 € considering 133 surgeries for the ultrasounds technique.

2.1.4 Discussion and conclusions

The present study compared vessel sealing systems and traditional hemostatic technique in order to assess the best technology to be used at the National Cancer Center G. Pascale. The clinical effectiveness was conducted on 49 papers available in the literature, selected and included in our study. The economic perspective was assessed performing the break-even point analysis.

Results of the HTA are summarized in Table 8.

Regarding the effectiveness assessment, the results showed that vessel sealing systems can reduce surgery duration compared to the traditional technique currently in use at the National Cancer Center G. Pascale. Particularly, the use of DRF technique can reduce the thyroidectomy duration of 13 minutes (average), while the ultrasounds technique of 24 minutes (average) compared to the traditional technique. Due to the low number of clinical studies on RRF systems available in the literature, we cannot state that thyroidectomy duration reduction of 3 minutes (average among 3 studies) is significant.

Overall results						
	Average surgery duration [mins]	Average hospital stay [days]	Average bleeding [ml]	Incidence of laryngeal nerves injuries [%]	Incidence of cases of hypocalcemia [%]	BEP [n. of surgeries]
Standard method	94.13	2.69	42.97	2.28	13.55	∀
RF disposable	81.35	2.18	31.54	2.52	9.84	29.08
RF reusable	91.43	3	N.A.	N.A.	6.5	25.65
Ultrasounds	70.31	2.8	31.46	1.64	10.66	182.59

Table 8 – Summary of HTA results

Furthermore, the results of this study showed that vessel sealing systems can reduce intra-operative bleeding and the incidence of hypocalcemia. On the other hand, no significant differences in terms of reduction of hospital stay and reduction of incidence of laryngeal nerves injuries were found.

The economic assessment was made studying fixed and variable costs of the technologies, and the incomes through the DRG linked to thyroidectomy. The break-even points were found for the three vessel sealing systems. The RRF system is associated to the lowest BEP (25.65 surgeries) among the techniques, followed by the DRF (29.08 surgeries). Even if they are more expensive compared to the traditional technique, the reduction of surgery duration may allow an increase of total surgeries per year. Indeed, both the DRF and the RRF techniques may guarantee cost recovery within 3 months.

Conversely, the ultrasounds technique is demonstrated to be not sustainable from the economic perspective by the G. Pascale hospital.

Moreover, based on the results of the literature, the RRF system is not often used in thyroidectomy, as also demonstrated by low number of the available clinical studies related to its use in thyroidectomy, while it is more often used for liver surgery and vaginal hysterectomy. The lack of a consistent number of clinical studies does not allow to assess the effectiveness of this technology in thyroidectomy.

Conversely, DRF and ultrasound systems are largely used in thyroidectomy and they are demonstrated to be effective, as shown by the literature. However, among the two, only the disposable RF technology is economically sustainable for the hospital. Nevertheless, more generally, it is worth considering that costs related newest technologies and their consumables, are usually more expensive compared to the technologies already on the market, and this cost is expected to decrease over time.

In conclusion, according to our analysis, the DRF technology appears to be an effective and economically sustainable option for thyroidectomy at the National Cancer Center G. Pascale. The economic sustainability of the DRF technology is even more reinforced considering the lower average surgery duration compared to the other technologies: the saved time, as already stated, might allow to increase the availability of the operating rooms and, consequently, the number of surgeries.

The methodology used in this work, essentially based on the identification of quantitative parameters from the literature for outcome evaluation and the successive costs' analysis, can be generalized and applied to different healthcare contexts, considering the specific constraints of the healthcare facility and the total number of surgical procedures, in order to identify the best technology to be adopted, in terms of outcomes and costs. However, a limitation of our study is the lack in the economic analysis of other direct costs related to the procedure, such as drugs, or other disposable medical device, that, for our purpose, may be considered negligible. In the future, once clinical data will be available in the literature, the study could be extended also to the excluded devices.

2.2 Assessment and design of innovative technology: GAMYCARE

Technologies not already in the market follow different methods compared to the ones presented in the previous paragraph. This branch of HTA is called "Horizon scanning". Horizon scanning is intended to serve multiple purposes, including, for example, the following [3]:

- Identify areas of technology change;
- Identify variations in use of technology;
- Forecast the health and economic impacts of technologies;
- Anticipate potential social, ethical, or legal implications of technologies;
- Enable health care providers, payers, and patients to plan for, adapt to, and manage technological change, including "rising"/emerging technologies.

Most horizon scanning programs generate rapidly completed, brief descriptions of new or emerging technologies and their potential impacts. As not much data is yet available in the literature, there are tradeoffs inherent in using early information that may be incomplete or unreliable. As a consequence, horizon scanning is often performed through "rapid reviews" (briefly introduced in the first chapter). Indeed, rapid reviews were proposed by some authors [105] as an important intermediary step in the assessment of emerging technologies, to be followed by a more comprehensive assessment. More generally, horizon scanning was defined by the Organisation for Economic Co-operation and Development (OECD) as "a technique for detecting early sings of potentially important developments through systemic examination of potential threats and opportunities, with emphasis on new technology and its effects on the issue at hand" and "it explores novel and unexpected issues as well as persistent problems and trends", whereas horizon scanning vision "is about exploring what the future might look like to understand uncertainties better" (gov.uk).

A comparative study exploring differences in the complexity and findings of rapid and full reviews evaluated as 11 the minimum number of criteria to be addressed within a rapid review [106]. In the same study, it was proposed that a rapid HTA should focus on the study question by exactly defining the technology, outcomes, and study population to be examined.

This approach (identification and design of the technology, focus on potential outcomes for the study population) was followed to perform the horizon scanning of a technology not yet on the market, designed in 2015 by the Clinical Engineering Group of the University of Trieste [47], [48], presented in the following paragraph.

It is important to underline that HTA reports (including Horizon Scanning) should be performed by external professionals, in order to avoid bias due to conflict of interests. However,

the present study can be considered as an exercise for enriching the design of an innovative solution through the application of horizon scanning approach.

Namely, an evidence-based approach was used, in order to study the state-of-the-art, underlying the current trend of emerging mobile technologies for healthcare. The review of the literature was not limited to the technological aspects, but it took into consideration also the best-practices and most advanced methods for supporting patients with chronic conditions. Moreover, in accordance with horizon scanning approach, the main issues of the solutions currently in use were identified. The output of this first step, allowed to select the most important features of an innovative technology, able to overcome the current issues and useful for patients. The most successful solutions already available in the market were then identified, filtered and compared with the proposed technology (approach similar to competitor analysis). Additionally, a preliminary assessment which involved 22 patients attending an outpatient Chronic Care clinic was performed, in order to assess the interest (declined in specific indicators) of the potential users.

The overall study followed the approach of exploratory scanning, as defined by [107], focusing on the main current issues, and the impact of an innovative solution (within an emerging area of healthcare technologies). The performed assessment is close to a "brief overview", defined as "in-depth but still brief overview" [108] that, following its definition, includes background on the technology, information on how it works, clinical burden of the disease, current comparators, costs, and social, ethical, and legal concerns. However, not all the areas included in the definition were included in the study. The performed assessment is nearly close to horizon scanning template provided by [108], and it is structured as follow:

1. Patient- and setting-related information: indications, specialty, patient numbers, setting for technology use, alternative or complementary technologies;
2. Technology-related information: name, description, company or developer, stage of development, type (e.g., drug, device), use (e.g., therapeutic, diagnostic), comparison with similar technologies on the market;
3. Impact predictions: health impact; ethical, social, cultural, and cost impact.

At the end of the assessment, some considerations on how the technology could affect current policy and practice are presented, in line with horizon scanning approach. Particularly, a summary of the above mentioned Horizon Scanning focal points.

2.2.1 Patient- and setting-related information

The area of interest investigated for designing the technology is related to patients with chronic conditions. Indeed, solutions for improving management of chronic conditions are under the attention of healthcare systems, due to the increasing prevalence caused by demographic change and better survival, and the relevant impact on healthcare expenditures.

For example, according to International Diabetes Federation (IDF) data, the absolute number of diabetics in the EU will rise from approximately 33 million in 2010 to 38 million in 2030. In 2010, approximately 9% of the adult (20-79 years) EU population was diabetic. Diabetes mellitus and its complications (including: diabetic retinopathy, kidney failure, heart disease, neuropathy and diabetic foot disease) have become a major public health problem in all countries. It causes significant physical and psychological morbidity, disability and premature mortality among those affected and imposes a heavy financial burden on health services. The prevalence of diabetes and complications can be reduced through early and appropriate intervention. Within Europe, important differences between potential risk factors (lifestyle, environmental factors, genetic predisposition, etc.) exist [109]. Morbidity rate and economic burden of diabetes in EU are 8.5% (estimation 10.3% in 2023). In particular, there are 3 categories of costs associated with diabetes:

- Directs costs: Diabetes is costly for the health care systems because of its chronic nature and particularly because of the gravity of its complications. Diabetes complications require hospitalization most of the time. 50% of people with diabetes suffer from at least one complication. Hospitalization represents the biggest proportion of the direct costs;
- Indirect costs: Diabetes causes a loss of productivity because of disability, sick leave, early retirement and premature death. Indirect costs are often higher (up to 5 times) than direct costs;
- Intangible costs: Diabetes influences the quality of life of patients (suffering, anxiety, and discrimination sometimes). It can also affect their social life and their leisure time. Their mobility can also be reduced because of the disease.

The typical severe events of diabetes are hypoglycemia and glycemic decompensation due to hyperglycemia. In order to avoid severe events, complications it is of paramount importance that the patient plays an active role in the care plan. The latter must include a program of diabetes self-management education, a useful process for the patient in order to acquire the fundamental skills to correctly interpret the symptoms and blood glucose levels and to take corrective action autonomously. In order to reduce the costs of treatment, to improve the quality

of life and to reduce the need for insulin in insulin-dependent patients, it seems necessary to accompany the care plan a medical nutrition therapy that takes in account the needs of the patient and a regular physical activity. It is recommended to include in the follow-up of the patient a psychological evaluation, because of the patient's distress and helplessness caused by the restrictions due to the disease. Patient-collected physiological data, such as blood glucose levels, glycated hemoglobin, and blood pressure, body weight should be monitored. Moreover, predictive models are available (e.g., Archimedes) but not often used. An adequate Decision Support System (DSS) should be provided to patients to empower the patient in self-management.

Another common chronic disease is heart failure (HF). It is a pandemic syndrome: it affects 2-3% of patients in the general population, with incidence increasing progressively with age and reaching 10-20% in aged population [110]. Male gender, advanced age, more severe symptoms, coronary artery disease, hypertension, impaired renal function, hyponatremia, and elevated plasma brain natriuretic peptide concentration are all factors associated with poorer prognosis. Despite HF prognosis has improved in the last decades, it remains very poor: near 50% of patients worldwide die within 5 years from diagnosis (remains worse than that of many common malignancies). The condition has a major impact on many aspects of an individual's quality of life, which is regarded as being worse in HF than in chronic lung disease, arthritis, or diabetes. The improving prognosis, coupled with a rapidly aging population, is driving a steep increase in the total number of people with HF: conservative estimates suggest that 6 million Europeans have this syndrome.

Moreover HF is tremendously expensive representing about 2% of national health expenditures. It is the primary cause of 5% of hospital admissions in Europe (20% after 65 years) and is present in 10% of hospitalized patients. Readmission rates are high: 30-40% of hospitalized patients are readmitted after one year (WHO reports 2011, ESC Heart failure guidelines 2012, AHA Heart Failure guidelines 2013). HF presents high direct and indirect costs (morbidity, unpaid care costs, lost productivity, premature mortality), with more than 60% of total cost related to hospitalization.

Although heart failure presents enormous healthcare burdens, outcomes are highly variable and predictive models may give important contribution to the patient assessment. Indeed, improving both in-hospital treatment and home care are the goals of HF management and their achievement can be measured assessing the impact in national health system of hospitalizations, emergency department accesses, non-scheduled cardiologic visits due to heart failure and patient stabilization, and Quality of Patient Life. To this end, score systems have been introduced

and some of those have been validated (e.g., Seattle Heart Failure Score, MAGGIC score), but predictive models are not often used in the clinical practices.

Regarding home care management of HF patients, much of healthcare utilization is thought to be preventable if patients engage in consistent self-care.

Many aspects of self-care monitoring have been evaluated and validated in heart failure management: 1) medication taking, 2) symptoms monitoring, 3) dietary adherence, 4-5) fluid and alcohol restriction, 6) weight loss, 7) exercise, 8) Smoking cessation, 7) preventive behaviors (such as influenza vaccination). Depression, anxiety, comorbid states, age related issues, incomplete disease knowledge are known factors that can make self-care difficult for the patient.

More generally, in their everyday lives, patients with chronic diseases deal with a range of conditions that require self-management and relevant decision-making. The attention to chronicity is acquiring worldwide relevance also because of the steadily increase in associated costs due to demographic changes and better survival rates of patients with chronic conditions [111]. The reduction of costs associated to the management of chronicity is one of the main challenges healthcare systems have to face.

Upon hospital discharge, the multidimensional aspects of patient's care converge into a combination of clinical conditions (co-morbidities, reduced functional capacity and self-sufficiency, depressive and anxiety symptoms), psychological needs (awareness, acceptance, redefinition of self, self-efficacy, empowerment), and social challenges (loneliness, family/social support) which may ultimately significantly affect patient's adherence and well-being [112].

Several approaches are currently being adopted to promote and sustain patient's adherence; among them, there is patient education (cognitive-behavioral individual and/or group interventions [113], nurse interventions, workshops, printed material, online communication); patient reminders (e-mails, tele-calling, text messages); pharmacy-based programs; collaboration with patient organizations, etc. Research has shown that the multifaceted aspects of adherence require multiple tactics to prove successful in time [114]. Between 2013-2016, Friuli Venezia Giulia Region has been leading a EU-funded, 24-region project on ICT-supported integrated care to provide domiciliary care to fragile, elderly European citizens. The experience has shared light on the needs and the maturity level of elderly citizens in the learning and use of technology and has highlighted patients' willingness to be actively engaged with their healthcare/social care teams in the management of their own health. Preliminary results show the empowering aspect of technology for senior citizens [115].

The implementation of mobile technologies may support a healthcare redesign based on disease management programs and integrated care models [116] [117] [118] [119]. Furthermore, mHealth technologies may act as a complementary tool to provide support and

motivation to regular patient's self-monitoring of health parameters (e.g., blood pressure, heart rate, blood glucose) [120]. The resulting empowerment may help patients to achieve personal health objectives, modify lifestyle patterns and/or high-risk behaviors for an optimal management of their chronic condition [121].

Currently, over 35,000 mHealth apps for different health conditions are available for iOS and Android platforms [122]. Nevertheless, many challenges are still to be faced, such as open architecture [123] [124], medical devices directive applicability and data protection [125] [126], interoperability and integration in existing healthcare models [124], [127]. Most mHealth solutions rely on an architecture that only addresses one specific disease and are usually either all-online or all-offline [128]. Furthermore, these applications have been developed independently as stand-alone applications and are not easily integrated into existing healthcare models. Success of mHealth solutions depends also on their ability to address and meet users' needs. The diversity of needs and requirements comes from different age, sex, pathology, health status, environment and professional and social activities. The adaptability of the system in terms of customization and personalization is of paramount importance. Moreover, among others, health-related data are one of the most sensitive issues, and they are being protected by laws and regulations. However, it is well known that digital data, especially in a mobile environment, pose a huge security risk in terms of privacy violation [128]. The protection of health data is still a mHealth burning issue, which has to be handled properly. Data collected by sensors and coming from other sources do not impact only on storage and transfer capacity, but also require the ability of the system to analyze a large amount of information. Clinicians and patients are not interested in single data, rather in trend and overall scenarios. Therefore, the development of an intelligent system for data analysis and Decision Support Systems is essential for helping patients along their clinical pathways [129].

Many DSSs are available in current literature, but they are seldom based on validated predictive models and even though some scoring systems have been validated (e.g., Seattle Heart Failure Score [130], Archimedes [131]), predictive models are not often used in clinical practices.

Moreover, beyond the above-mentioned considerations, a crucial aspect needs to be tackled anytime an IT solution has to be developed, i.e. the psychological and social implications of the new technology from the patient's point of view. In order to answer these needs, a suitable approach must be found for meeting three major requirements: increasing self-management, self-awareness and social inclusion of patient/s within their communities.

Actually, self-management may reduce the number of severe events (e.g., hypoglycemia and glycemic decompensation due to hyperglycemia in case of diabetic patients), thanks to the active role played by patients in their care plan. Furthermore, educational programs concerning, for

example, self-management education, acquisition of the fundamental skills to correctly interpret the symptoms and to autonomously take the relevant corrective actions are of paramount importance [132].

Secondly, self-awareness is being considered increasingly important. Self-monitoring has shown to enhance self-awareness and plays a substantial role in most behavioral programs aimed at promoting patient's adherence to therapy [133]. Research shows that people judge a risk not only by what they think about it but also by how they feel about it. If their feelings toward an activity are favorable, they tend to judge the risks as low and the benefits as high; if their feelings toward the activity are unfavorable, they tend to make the opposite judgment, i.e. high risk and low benefit [134]. Interventions aimed at improving user's risk perception need to draw their rationale on the understanding of the psychological mechanisms and relevant theories underlying human behavior and motivation, in order to bring effective and long-term outcomes.

Finally, social inclusion plays a key role in understanding, accepting and handling the complexities of change which are inherent to a life-limiting chronic illness [135].

In this process, positive communication is essential: in fact, whilst perceived negative change may lower self-esteem and hinder self-care, positive handling of change may increase self-awareness, self-worth and boost self-management skills.

Summarizing, the main issues above mentioned highlighted at the state-of-the-art are related to open architecture, interoperability and integration, compliance with medical device directives and data protection, customization and personalization, DSSs based on validated predictive models as well as psychological and social implications. The target of the evaluated technologies regards those for patients affected by the most frequent chronic conditions (e.g., diabetes, HF) with no severe mental and physical disabilities.

A detailed description of the most important features an emerging technology for patients with chronic conditions should address, with particular attention to patients' needs and in accordance with the most recently findings and emerging techniques, is presented in the following subsections.

Mindfulness

Mindfulness has been defined as a kind of non–judgmental, present-centered awareness in which each thought, feeling, or sensation arising within the perimeter of our attentional field is acknowledged and accepted [136]. Within this process, the person moves toward a state in which one is fully observant of internal and external stimuli in the present moment, and open to

accepting rather than trying to change or judge whatever arises to their conscience [137]. Baer [138] suggests that mindfulness may promote exposure to previously avoided internal experiences, thus promoting cognitive change or a shift in attitude about one's thoughts, while at the same time increasing acceptance. According to Teasdale and colleagues [139], mindfulness practice may increase metacognitive awareness, a process through which negative thoughts and feelings are experienced as mental events rather than as the self. Moreover, a mindfulness-based approach has been incorporated within dialectical behavior therapy [140]; the combination of training and implementation of mindfulness meditation with cognitive therapy has been seen to significantly reduce relapse rates in recurrent major depression [141].

Mindfulness goes beyond the simple practice of meditation; in fact, meditation practice is simply a "scaffolding" used to develop the state, or skill of mindfulness [142]. Meditation is also often recommended as a practice that can be applied as a stress-reduction procedure to deal with a variety of health-related problems such as pain management, hypertension, and cardio-vascular diseases [143]. There is an increasing number of studies of acceptance, mindfulness, and values-based action in relation to chronic pain. Also, whilst cognitive-behavior therapy (CBT) has proved its effectiveness in treating depression and anxiety disorders [144], a 2012 Cochrane review [145] outlined that only 38-77% of patients suffering from chronic pain responded to CBT by experiencing clinically significant relief. Mindfulness-Based Cognitive Therapy (MBCT) may thus prove effective by its four-stage therapeutic approach which is designed to help people modify their thought process rather than the mere content of their thoughts [146]. Within a beehive person-centered approach [115], whereby each person is at the center of an integrated process of mutual care, mindful empowerment may thus turn out to be a pivotal issue in the development of innovative solutions for patients with chronic disease.

Social inclusion

Healthcare delivery is presently mainly focused on face-to-face interactions. However, mobile technology may act as a complementary tool to provide support and motivation to regular patient's self-monitoring of health parameters (e.g. blood pressure, heart rate, blood glucose, etc.). Social media may help decrease the burden of a chronic disease and become eHealth partners by providing Care Recipients with real-time access to care and social support. The resulting empowerment may help Care Recipients to achieve personal health objectives, modify lifestyle patterns and/or high-risk behaviours for an optimal management of their chronic condition. When Care Recipients are networked with each other through social media platforms, they shift from being passive recipients of healthcare to being active actors. Thanks to

the ubiquity of mobile devices, social media networks may provide unique social support, by combining motivation and education for patients suffering from a chronic illness.

However, from an ethical perspective, this is an important aspect to consider. Indeed, technology may also cause dependence and isolation from the outside world. To this end, it is of paramount importance, trying to find ways for letting patients interact each other in a real context. From this perspective, mobile technology should be exploited as a mere tool for increasing social inclusions and independence, even from the technology itself.

Gamification

Gamification has a good impact on motivating users' behaviors; it also plays a crucial educational role, since motivation is one of the basic conditions to learn. Moreover, it has also been proven successful for empowering patients to adopt healthy lifestyle [147]. Gamification mechanics are already represented in several mHealth applications and are an encouraging implementation for incentivizing improved patient self-management [148] [149]. It has also been reported that gamification improves engagement, compliance to therapy and learning [150] [151]. Furthermore, gamification alone or with social support may increase physical activity and empowerment and decrease healthcare utilization [152].

As far as the anxiety experienced by patients with chronic disease, the theorystates that the underlying causes of anxiety disorders may be found in a dysfunctional cognitive bias, whereby the individual develops an over tendency to pay attention to danger, ignoring any sign of safety and/or pleasure. This fearful state of mind determines what is called 'skewed attention'. In order to modify this dysfunctional attention bringing to anxiety and stress, non-threatening gamification-supported competition is developed to train the subject away from threat/danger cues [153]. In fact, games can be used to drive positive change in health-supporting behaviors by rewarding players for accomplishing desired tasks (positive reinforcement) and by taking advantage of natural competitiveness within a friendly, mutually supportive environment. In order to avoid "nagging effect", constructive messages are provided to support individual and group motivation so as to boost user's self-esteem and reinforce positive behaviors.

Education

As previously introduced, education plays a crucial role in patients with chronic conditions. Indeed, review of the literature [154] demonstrates that education increase patient compliance (average improvement = 0.67σ over control, $p < 0.05$), and improve physiological progress (0.49σ, $p < 0.01$) and health outcome (0.20σ, $p < 0.05$).

Decision Support System

Currently, many practitioners use validated medical predictive models related to the selected chronic conditions and medical guidelines (e.g., Diabetes: Archimedes [131], EAGLE [155], GDM [156] and ADA guidelines [157]; HF: Seattle HF model [130], MAGGIC [158] and European Society of Cardiology guidelines & education).

Decision Support System is increasingly used, since it may improve patients' health status. Indeed, review of the literature [129] demonstrates that Decision Support System has been proven to significantly improve clinical practice in 68% of trials. Moreover, it may improve chronic disease management which requires recurrent visits to multiple health professionals, ongoing disease and treatment monitoring, and patient behavior modification [159].

2.2.2 Technology-related information

The name of the assessed technology is GamyCare, an innovative mHealth solution, aimed at boosting the active and informed participation of patients in their care process, overcoming the current technical and psychological/clinical issues highlighted by the existing literature. It was designed by the Biomedical and Clinical Engineering Group of the University of Trieste in 2015. It can be considered as an emerging technology, since it is currently being developed.

A detailed description of the technology is provided in the present section, in accordance with the aforementioned clinical, psychological and social needs (e.g., patients' self-management, self-awareness, empowerment, social inclusion, positive communication).

Mindfulness

GamyCare answers the need for increasing self-awareness through the integration of mindfulness.

GamyCare supports a mindfulness-based intervention through a tailor-made path so as to allow beginners to incorporate mindfulness practices in their everyday lives. As with any other intervention, mental health pre-screening and regular supervision need to be carried out by the clinician so as to rule out the presence of mental disorders which may put the patient at risk. The specific path (in terms of "entry level") is evaluated by administering the Five-Facet Mindfulness Questionnaire [138] to the patient, designed to assess a core characteristic of dispositional mindfulness [160].

This approach takes into consideration specific patient's needs allowing system personalization. The overall path of the approach is listed below:

- Awareness of the five senses;
- Visualization exercises (e.g., bodyscan);
- Mini-guided meditation sessions;
- Daily reminders to bypass the risk of alarm fatigue so as to promote adherence;
- A motivational calendar to enhance self-care and prosocial behavior;
- The user will become part of a mindful community which reinforces each other's behaviors and enhance both individual's and social healthcare responsibility;
- Successful adherence and behavior modification will be signaled to the user through easily readable health indicators which will provide cognitive and emotional reinforcement.

Piazza Grande

GamyCare enhances the importance of social inclusion of patients affected by chronic conditions in the real life through the implementation of Piazza Grande. Piazza Grande is a virtual meeting point where calendars of city health-promoting events can be shared, thus providing a means to meet in real life and share experiences (e.g., diaries and pictures) with those care recipients who are unable to join due to their serious health conditions. Particularly, Piazza Grande serves as a gateway to the people who matter to the patient/user and also connects individuals with the same conditions. Several interactions can be made between among subjects to improve engagement and reduce loneliness in some scenarios. Mindfulness may be promoted and enhanced within the virtual group of users, by sharing not only experiences, but also moments of practice and mutual support along the lines of social learning [161]. Not only patients can access to the Social Network Piazza Grande, but also all the people in their "real-life network" can be part of it, such as healthcare professionals, relatives, friends, caregivers. Piazza Grande may also benefit from the support provided by the Third Sector (e.g., college students enrolled in medical and/or nursing schools) who may, in turn, learn better and more effective ways to take care of their own health and well-being. This may actually promote healthier lifestyles among a wider community of 'healthy' users. To this end, different access levels will be defined in order to guarantee the privacy of the patient. In a person-centered solution, patients can be connected to the people who care for their health and who can help them learn self-management and accountability skills.

Figure 4 - Network Model of Care included in Piazza Grande

Gamification

GamyCare is based on gamification to promote patients' self-management and enhance their empowerment.

The gamified approach is carried out in both passive and active ways: in the first one, by using a gamified virtual representation of their health status avatar (VHA), the patient watches (and reacts) as that persona represents their own health, enhanced also with the support of the DSS. Furthermore, the automatic measurement of biosignal data is translated into changes on the VHA. The active way represents a more direct approach of the gaming concept, i.e. this pertains to activities that the patient/user consciously comprehends to be games: challenging another user to a jogging or cycling game, a trivia competition about a particular condition, compare recent healthy lifestyles and be rewarded, etc.

Scope of the mindfulness-based gamification approach is to promote users' perception and awareness of risks while simultaneously reinforcing risk prevention user's-led behaviors through a set of easy-to learn, simple-to-use and noninvasive techniques which may promote individual's awareness, empowerment, and role modeling.

Education

GamyCare educates and trains patients both to learn about their pathology and to better understand how mindfulness and the other integrated tools may help them in improving their quality of life. The concept behind GamyCare approach is that the more patients know about their condition, the more they can better manage their health, also in terms of self-management and promotion of adherence to therapeutic prescriptions and healthier behaviors (decreasing the risk behaviors and risk factors). The educational contents are shared with patients through different tools and interaction modalities (video, audio, text) in the user's mother tongue, and the educational content is tailored to the patient's background in accordance with the preliminary assessment results. Moreover, through a self-regulated learning process, patients can select the goals (challenges) they want to reach, following a gamified approach.

The patient/user can constantly access a detailed and comprehensive database of information about their conditions, as well as relevant updates concerning, for example, new important findings. Moreover, training and education are provided with a positive approach in accordance to the mindfulness and gamification concepts.

Decision Support System

To empower patients to participate in the management of their health through applications for their disease, lifestyles and prevention monitoring, it is necessary to increase their consciousness about their health conditions and risk awareness. To this end GamyCare provides users with a personal monitoring system empowered by a Decision Support System which provides feedback about their health status, predicts health evolution and provides patients with warning alerts. The patient-specific data (e.g., biomedical, clinical, therapeutic, environmental, social data) are processed in real-time by prognostic and diagnostic algorithms based on artificial intelligence and computational models. These models and algorithms include validated medical predictive models. The prediction is accompanied by personalized suggestions which encourage patients to healthier behaviors and lifestyles. Moreover, the implemented DSSs generate medication reminders and warn patients on the consequences of non-adherence to the prescribed protocol.

GamyCare aims to boost the use of existing validated predictive models by implementing them into a comprehensive mHealth solution supported by gamified representation and prediction of health status, and also by providing relevant recommendations based on clinical guidelines. Thus, models' outputs may become more useable and understandable to the patient thus increasing their everyday use and diffusion. The lack of large validation clinical trials and

the shortage of personalized validated predictive models are problems that still need to be tackled.

Preliminary Patient Assessment

In order to assess in a real life context the need for a support to self-management and to lifestyle improvement, and in order to evaluate the acceptance level of our technological solution designed to relieve chronic disease burden, narrative medicine semi-structured interviews and Psycho-Social-Assessments (25 questions on physical, psychological and social well-being on a 5-item Likert scale rated on intensity/frequency of experience) were administered to a random sample of 22 patients, stratified by age and sex, attending the Chronic Care outpatient clinic at the Cardiovascular Center of Health Authority n°1 Triestina (Trieste, Italy). The sample of the interviewed patients was composed by 85% males and 15% females (mean age 76±9) with 8.5 (±3) years of education. 44% suffered from atrial fibrillation and 92% were in polytherapy with at least 4 medications. Furthermore, comorbidities included type II diabetes in 85% of patients, moderate to severe renal failure in 16%, hypothyroidism in 20%, and COPD (Chronic Obstructive Pulmonary Disease) in 8% of them. Patients had been previously screened and tested negative for cognitive and memory impairments. The semi-structured interviews were built on a grid which focused on the experience of illness, relationships with healthcare providers, supportive role of social network, beliefs concerning illness and adherence, self-awareness in everyday life, self-efficacy, self-report of mindful day-to-day experiences, empowerment/disempowerment, attitudes and behaviors related to adherence to therapeutic regimens and lifestyle changes, as well as technology-related attitudes and beliefs. Each narrative interview was audio-recorded and transcribed verbatim. Guidelines for grid construction in the domains of self-awareness and self-empowerment included questions from the MAAS (Mindful Attention Awareness Scale) which assesses dispositional mindfulness, (i.e., receptive awareness of and attention to what is taking place in the present) and from the PAM (Patient Activation Measure) which assesses patient knowledge, skills, and confidence for self-management [50].

The questionnaire results are summarized in Figure 5. As it is shown, 80% of patients with a chronic cardiovascular (CV) disease have difficulties staying focused in their everyday experience; 78% reported trouble in adequately responding to shifts in the environment and 55% stated that they have trouble noticing distressing thoughts without having an emotional/physiological reaction. The majority of interviewed patients (73%) felt disempowered as far as decision-making on health issues and treatment is concerned, and 76% of patients mistrust their self-care abilities. Interestingly, despite the advanced age of the sample,

60% of patients expressed either knowledge of, or interest in new communication technologies (e.g., mobiles, web-learning, social platforms).

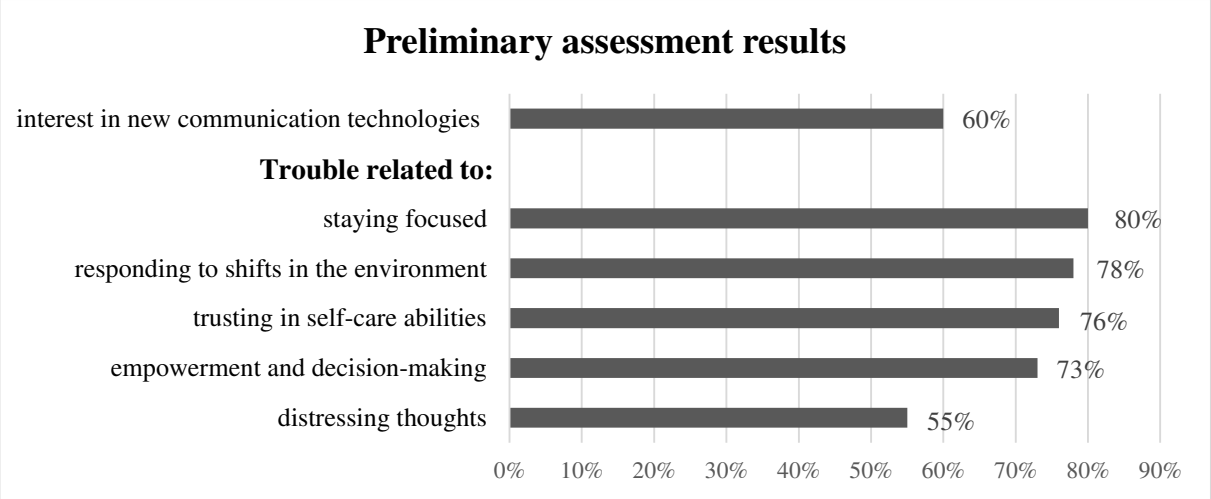

Figure 5 - Results of the preliminary assessment (from [47])

Though limited in scope, this qualitative screening sheds some light on the evolving needs for self-awareness and empowerment of patients suffering from chronic care conditions and has reinforced our approach to design the most effective solution for patients with chronic conditions.

2.2.2.1 Overall architecture

In order to establish an advanced system to monitor and support patients with chronic disease, GamyCare has been designed to meet the following technical requirements, considered important aspects as stated in our introduction:

- Open architecture in order to provide a scalable system, customizable to patients affected by different chronic diseases;
- Compliance with transfer and data protocols to ensure interoperability with existing wireless devices;
- Application of semantic web approaches and standards to ensure correct sharing of information with hospital information system, and classification of patient behaviors;
- Compliance to the existing standards and regulations;
- Guarantee security and privacy protection of health and personal data.

Each module of GamyCare architecture is shaped on specific patient's disease and condition states, so as to provide each user with a personalized solution. Even though the modularity can introduce limitations (e.g., increasing size and mass due to some redundancy and using standard components designed for more general applications), it allows customization, scalability and applicability to different kinds of chronicity.

Furthermore, the security, safety and interoperability of our technology are guaranteed through the compliance with existing standards. Notably, it is compliant with the ISO/IEC 27001:2005 which provide best practice recommendations on information security management, risks and controls within the context of an overall information security management system (ISMS). Moreover, data acquisition is compliant with data transfer protocols (e.g., BT4/LE, ANT+, ISO/IEEE 11073) in order to ensure integration with existing wearable devices. Patient's data are stored in accordance with privacy and safety legal requirements through the application of standard communication protocols (e.g., HL7, ICD-10 and openEHR) to ensure correct information sharing with hospital information systems and, eventually, Electronic Health Record (EHR).

In order to comply with the identified needs and requirements, the overall architecture (shown in Figure 6) can be divided into two parts: patient side (mobile) and server side.

Patient side and server side are both based on 3-tier architecture involving three physically separated layers: Presentation (or Client) Tier is the user interface. On the patient side, it is based on the gamification technique both for presenting and collecting data; on the server side, the view level of collected and processed data depends on the role of the logged user (i.e., healthcare professional, caregiver); Business Logic (or Application) Tier coordinates the application, processes commands, make logical decisions and evaluations, and performs calculations. It also moves and processes data between the two surrounding layers (Presentation and Data Tiers); Data (database) Tier stores and retrieves information, which is passed back to the Logic Tier for processing. Particularly, on the server side, data are permanently and safely stored, in compliance with the requirements for guaranteeing user's privacy; conversely, on the patient side, data are transitory since the database is a buffer filled with data coming from the server and the newest acquired data which are subsequently sent to the central database.

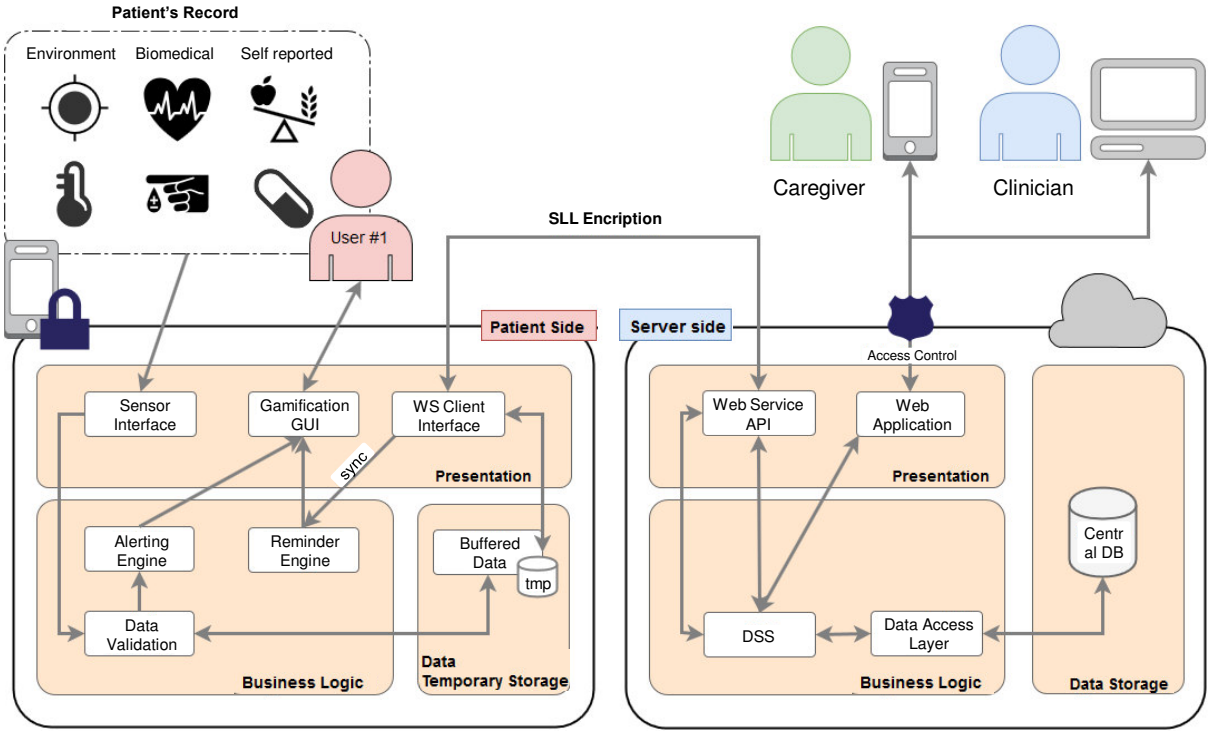

Figure 6 – Overall Architecture (from [47])

On the patient side, a mobile application provides features and services to the patient. Through the gamification GUI module, better patient's self-care may be promoted and enhanced. Data which are automatically collected by biomedical and environmental sensors through the sensor interface, as well as self-reported data, are validated to provide real-time risk warnings/alerts whenever recorded values are out of range of safety, even when internet connection is not available. Particularly, Internet connection allows for buffered collected data to feed the DSS on the server side and to obtain remote health status monitoring and prediction of health evolution, accompanied by behavioral, lifestyle suggestions and social support provided both by caregivers and clinicians. Therapeutic reminders are also ensured in case of Internet service interruption. As sensitive data, they are being stored in the central database. However, a message reminder is locally scheduled on the Patient's device without therapy explicit references. Connection is needed to view the full text reminder with therapeutic details. A reminder engine collects all the important reminders (e.g., scheduled appointments, drugs reminders, diet, and lifestyle suggestions) and it is synchronized with the central database on the server side when Internet connection is restored. Synchronization, remote support and feedback on therapeutic compliance are only some of the features that are provided to the patient through

the web services API. This API represents the interface module between the web service client interface on the patient side and the server side. The API also manages SSL encrypted traffic made up of all medical history and other sensitive data, interactive educational tools and contents, and social network interactions.

No personal and/or sensitive data are stored on the patient's device. Historical data are stored on the central database. Conversely, the newly acquired data are used for urgent advices and not for consulting scope and, to this end, they are available in off-line mode until the connection is restored. Those data are temporarily stored in the buffer module after their validation. This also allows better management of a large amount of information, since data are only stored in the central database receiving and sending out necessary data on demand.

On the server side, as already briefly stated, patient's data are stored and monitored. Caregivers and healthcare professionals get patient's health information through the web application module where aggregated data and graphs, processed by the DSS module, are presented and defined in accordance with different levels of users' access. The DSS is the most important module of the business logic tier, and it is based on a relational database management system where data are stored in a disease-centric manner, as it is shown in Figure 6. The connection of this database is handled by the Data Access Layer that also grants access to its data.

The Entity-Relationship model of the database is represented in Figure 7. Particularly, the entity *Disease* represents the core of the system and it is managed by a specific *DSS module*. *Disease* is linked to one or more *Professional* (e.g., health specialist), and *User* is linked to one or more *Disease*. Each user can be followed by zero or more caregivers (e.g., relatives, friends) and also follows the mindfulness program starting from the appropriate level in accordance to their background. Mindfulness programs and DSS modules provide users with suggestions, exercises, and educational contents. In the database architecture, *Patient's Record* (e.g., self-reported data) are linked to a specific *Disease* and can be required by *DSS Module* and *Mindfulness Program* through *Suggestion & Exercise*, should patients be required by the system to perform measurements or other tasks, or provide feedback. Possible *Signal DataSet* resulting from the processing algorithms are stored as "children" of correspondent *Patient's Record* (e.g., biomedical and environmental signal).

This overall database architecture allows DSS to define the proper contents to show according to the tracking progression of patient's status. Moreover, Disease centrality permits to easily connect Users, Caregivers, and Professionals in the same area of interests (through the "location" attribute, based on GPS).

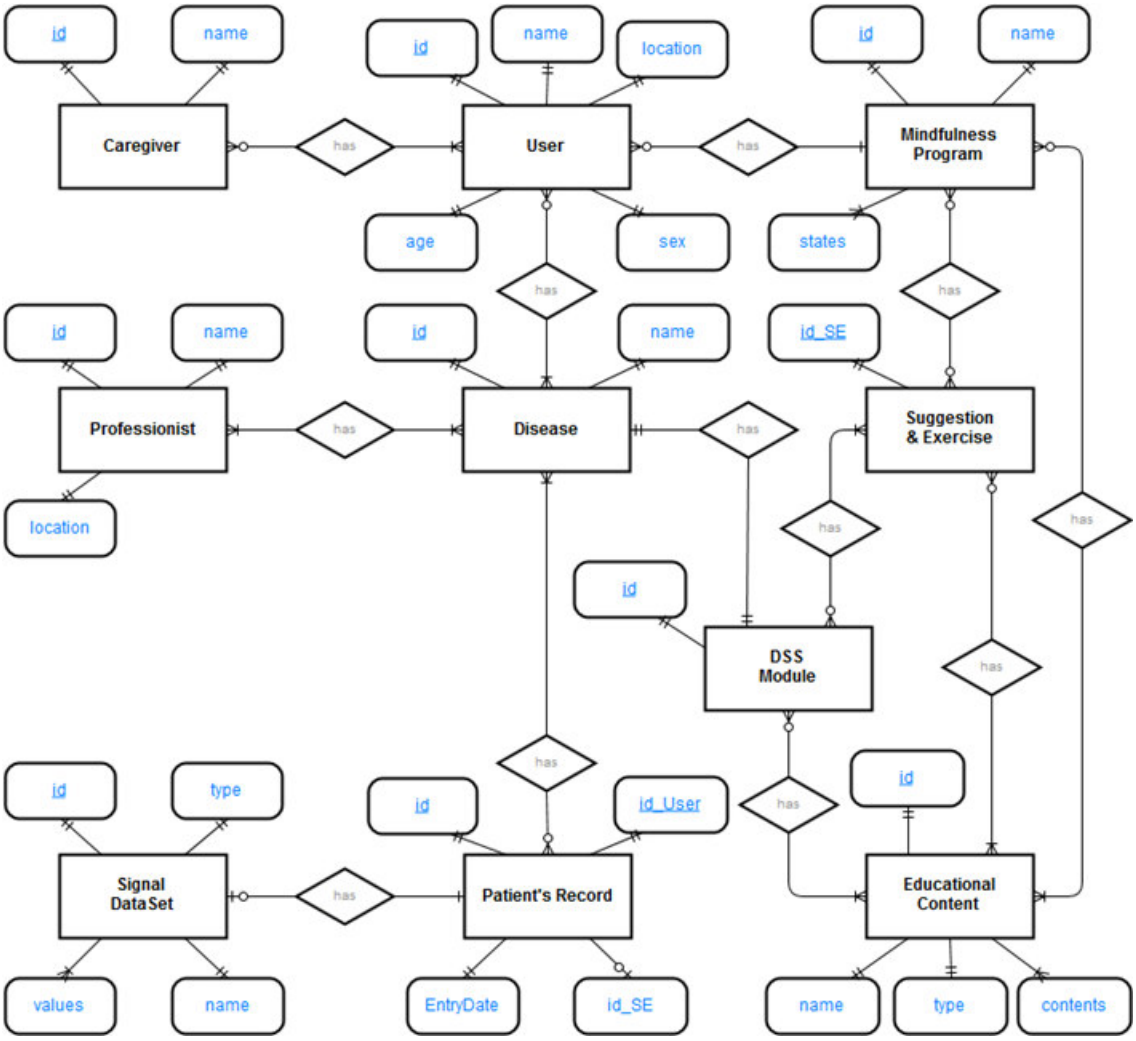

Figure 7 - Database architecture: Entity Relationship (ER) model of the database (from [47])

2.2.2.2 Comparison with similar technologies

Table 9 presents a comparison of GamyCare with similar technologies already in the market. Some indicators, considered important at the state-of-the-art and identified by the JRC European Commission as major gaps of technologies currently on the market were selected, providing an overview of the assessment. The indicators correspond to the criteria considered in HTA and they are 13 (more than 11, as it is the minimum number within a rapid review, as discussed in the introduction of Paragraph 2.2)

	validated clinical knowledge		data processing			interfacing and interaction		interoperability		social inclusion		awareness and self-management	
	integration with clinical evidence and guidelines	Prediction of health status	personalized data-processing	"multi-sensors" "multi-diseases"	Health status monitoring	multichannel delivery and interaction	education on how to use	with external medical device	with Electronic Patient Record	Social Network	Social Inclusion Real World	methods for increasing awareness	mechanisms for Self-management enhancement
patientslikeme	✗	✓	✓	✗	✓	✗	✓	✗	✗	✓	✗	✓	✓
glooko	✓	✗	✗	✗	✓	✗	✗	✗	✓	✗	✗	✓	✓
mySugr	✓	✓	✓	✗	✓	✓	✓	✓	✗	✗	✓	✓	✓
bloodpressurecompanion	✗	✗	✗	✗	✓	✗	✗	✓	✓	✗	✗	✓	✗
RunKeeper	✗	✗	✓	✗	✓	✓	✓	✓	✓	✓	✗	✓	✓
Metria™ Wearable Sensor	✗	✓	✓	✗	✓	✗	✓	✓	✗	✗	✗	✓	✗
MOTICON	✗	✗	✓	✗	✓	✗	✓	✓	✓	✗	✗	✓	✗
nuubo WEARABLE MEDICAL TECHNOLOGIES	✗	✗	✓	✗	✓	✗	✗	✓	✓	✗	✗	✓	✗
IndiGO™ Individualized Guidelines and Outcomes	✓	✓	✓	✗	✗	✗	✓	✗	✓	✗	✗	✓	✗
GamyCare	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 9 – Features (gaps underlined by the JRC European Commission) addressed by GamyCare compared with other solutions available in the market

According to the main purpose of GamyCare to overcome the current limitations at the state-of-the-art, as shown in Table 9, GamyCare was designed to be compliant with all the features underlined as major gaps the JRC European Commission. Indeed, it provides integration with clinical evidence and guidelines adopting know-how of medical guidelines and validated

medical predictive models. The latter ones allow also to predict the health status according to the data acquired by the system. This is possible thanks to the personalized processing of data collected through multiple sensors and directly inserted by the user, according to their specific disease. This results in a continuous monitoring of health status of patient. GamyCare was designed for overtaking limitations related to channel constrains, providing multichannel delivery and interaction (e.g., audio, and visual), allowing patients to choose channels according to their preferences. Moreover, before starting to use the technology, it provides simple guide with instruction on how-to-use the device, providing tips and suggestions. Even though it is currently only designed, GamyCare will be developed with a particular attention for being compliant with external medical devices and electronic patient records, assuring its interoperability. Another important aspect GamyCare will take care of, is social inclusion of patients both through social networks and in real world, underlying the importance of considering the technology as a mere tool for improving real life. Lastly, the integration of mindfulness and gamification will provide a support for increasing awareness and enhancing self-management respectively.

2.2.3 Impact predictions

In accordance with the main features presented in the previous sections, GamyCare may provide relevant impacts in terms of improving patients' quality of life, social life and awareness; enhancing adherence to therapeutic protocols; improving self-management of their chronic diseases; reducing economic expenditure.

Impact predictions have been studied qualitatively and, together with an example of cost reduction, are described as follow:

- Improving the management of a disease by reducing the number of severe episodes and complications: better disease management will be promoted through the support of GamyCare technology to enhance clinical and psychological self-monitoring and self-care skills while reinforcing health-promoting individual and social behaviors;
- Increasing the importance of the prevention sector in healthcare using predictive modeling: better disease prevention will be promoted through the support of DSS, based on predictive models, and interactive education, to enhance clinical and psychological self-monitoring and self-care skills while reinforcing health-promoting individual and social behaviors;
- Improving the participation of the patient in the care process: innovative gamification-supported mindfulness-based interventions, in synergy with PDSS, will

promote patient's motivation and active role in self-management to improve health behaviors (exercise, cognitive symptom management, communication with physicians), self-efficacy and health status, and increase their participation in the care process. The program will incorporate modeling and social strategies so as to enhance a sense of personal efficacy and empowerment;

- Boosting the development of personal devices used for self-management of health: GamyCare will hardness the potential of latest technologies and new social communication forms with self-management person and people-centered interventions. In addition, the personalized PDSS will enhance a patient-oriented approach, boosting personal devices used for self-management of health;
- Improving individual self-control of health and of disease prevention: GamyCare innovatively addresses self-management issues by combining technology-based support with a gamification and mindfulness-based cognitive-behavioral approach to increase risk perception while at the same time promoting awareness and proactive individual and social health-enhancing behaviors;
- Improving patients' interaction with others in the real world: the implementation of "Piazza Grande" will allow patients to feel more comfortable with their chronic disease through the support of persons sharing the same challenges;
- Exploiting device features without creating technology-dependency: the main aim of GamyCare is to avoid user technology-dependency. This is the reason why particular attention is dedicated to Piazza Grande and automatic suggestions provided by the app aim to enhance patients' autonomy in the real world;
- Reduction of economic impact: a recent systematic review [162] states that integrated care models for patients with chronic diseases have a positive economic impact. For example, an America study [163] reported that total medical costs decreased by 26.8% from the baseline period, after the introduction of a diabetes disease management program that considers only a limited number of parameters to monitor. GamyCare does not only provide patients with a disease management program, but it also integrates methods for increasing awareness and well-being, thus leading to hypothetical results even more effective and cost-saving. However, applying a conservative approach of a cost reduction equal to 20%, and considering that the annual expenditure per case for diagnosed diabetes (type 2, less costly than type 1) is $ 9,677 [164], GamyCare may allow to save $ 1,935 per patient per year. Moreover, considering that diabetes prevalence is approximately 27.5 million people in the United States [165], the total cost-saving in the United States can be estimated

as more than $ 4 billion per month. The cost of GamyCare can be estimated as $ 10 per patient per year, that is equal to $ 275 million per year. This esteem is certainly just an approximation that must be deepened, but it is sufficient to provide brief information on the economic assessment.

2.2.4 Assessment summary

The present section summarizes the most important information required by Horizon Scanning approach, as introduced in paragraph 2.2.

Particularly, Table 10, Table 11, and Table 12 present patient- and setting-related information, technology-information, and impact prediction respectively, detailed described in each specific section of the present paragraph.

Patient- and setting-related information	
Indication	Incidence of patients with chronic conditions is increasing and technologies for improving both therapy programs adherence and self-management resulted to be effective. Programs for improving awareness through mindfulness and education, well-being through social inclusion, adherence through gamification and decision support systems, resulted to be successful
Specialty	Patients with chronic conditions, especially diabetics and hearth failure
Patient numbers	Diabetics: 9% of the total population. Hearth failure: 2-3% of general population (10-20% in aged population)
Settings for technology use	Patients in their everyday life
Alternative or complementary technologies	Most of the current solutions mainly focus on in person interaction with physicians and healthcare professionals, such as patient education (cognitive-behavioral individual and/or group interventions, nurse interventions, workshops, printed material, online communication); collaboration with patient organizations. Tools for improving patients' adherence to therapeutic programs are usually based on patient reminders (e-mails, tele-calling, text messages)+. Tools for supporting practitioners for a better management of chronic diseases are based on validated medical predictive models and medical guidelines

Table 10 – Summary of patient- and setting-information required by Horizon Scanning approach, as presented in paragraph 2.2, extensively described within the present chapter

Technology-related information	
Name	GamyCare
Description	GamyCare aims to provide mobile, web-based tools and devices to keep patients with chronic diseases away from severe episodes and complications of illness, to improve their quality of life and to reduce their economic impact by promoting risk prevention, self-management of the chronic condition, and decision-making. GamyCare is hence designed to boost the active and informed participation of the patients in their care process, allowing them to manage their own health and increasing their awareness
Company or developer	University of Trieste, Biomedical and Clinical Engineering Group
Stage of development	Emerging technology
Type	Mobile app, web-based tools
Use	Therapeutic
Comparison with similar technologies	GamyCare was designed to overcome the current limitations at the state-of-the-art, and it has a competitive advantage compared to the similar technologies available in the market

Table 11 – Summary of technology-information required by Horizon Scanning approach, as presented in paragraph 2.2, extensively described within the present chapter

Impact predictions	
Health impact	Improving the management of a disease by reducing the number of severe episodes and complications
Health impact	Increasing the importance of the prevention sector in healthcare using predictive modeling
Cultural impact	Improving the participation of the patient in the care process
Cultural impact	Boosting the development of personal devices used for self-management of health
Cultural impact	Improving individual self-control of health and of disease prevention
Social impact	Improving patients' interaction with others in the real world
Ethical impact	Exploiting device features without creating technology-dependency
Economic impact	Sensitive reduction of economic impact

Table 12 –Summary of impact predictions required by Horizon Scanning approach, as presented in paragraph 2.2, extensively described within the present chapter

2.2.5 Discussion and conclusions

The approach of Horizon Scanning for designing an innovative technology, allowed to focus on the most important aspects to be considered for creating a competitive solution. Even though, as already stated, Horizon Scanning should be performed by external professionals in order to

avoid conflict of interests, the research resulted to be of help during the identification of the main features to be implemented.

Particularly, the open architecture and approach offered by GamyCare were thought to overcome the main limitations of the present solutions available on the market, in terms of technical requirements (e.g., standards for interoperability and privacy) and humanistic and psycho-social needs (e.g., Piazza Grande). Regarding the latter, the integration of the DSS aims at improving the compliance of patients with their clinically devised pathway. With a view to strengthening the link between users and their health, the gamification approach has been introduced as an additional technique. Moreover, the enhancement of a positive psychological status, self-awareness and, consequently, quality of life is obtained through a mindfulness-based, self-empowering approach. Furthermore, the results of our preliminary assessment show the evolving needs for self-awareness and empowerment of patients suffering from chronic care conditions. The interviews' and questionnaires' results show patients' need to increase self-empowerment and self-awareness and, at the same time, their interest in new communication technologies. Nevertheless, this preliminary assessment presents several limitations (e.g. small sample, elderly patient population, high specificity and severity/complexity of disease). Even though innovative cognitive-behavioral programs may promote awareness of self and support educational and clinical interventions, careful identification of the most adequate patient population (e.g. according to age groups, complexity and/or severity of disease as well as computer literacy) is advisable so as to maximize intervention outcome.

Considering also the economic impact of the proposed solution, the described design should be developed in a short time, maintaining the competitive advantage.

2.3 Final remarks

Conducting assessment of medical devices resulted to be different among the two considered technologies. Indeed, for the first assessment (technology already in the market), data of clinical outcomes (e.g., effectiveness) were available in the literature and comparison with other technologies was possible to undertake. The analysis was conducted in accordance with the most recent HTA approaches that focus primarily on providing evidences in a short time, instead of providing more robust statistical results with longer studies. This can be considered as a limitation of the study, even though it is worth reminding that the primary goal of the overall study was to provide a useful tool as a compromise between scientific approach and practical usage. Further analysis can be conducted using Multi Criteria Decision Analysis approach, identifying the most important criteria to be considered for assessing the best technique to be used in thyroidectomy, and involving a multi-disciplinary group of stakeholders.

The second assessment (GamyCare) was more difficult to be compared with other technologies, since the proposed solution is not yet in the market. This resulted in an assessment that is closer to a market analysis, instead of an HTA. However, the Horizon Scanning approach described at the beginning of the chapter was followed. This allowed to identify the most important features to be considered for an innovative solution, aimed at overcoming the current limitations at the state-of-the-art, focusing primarily on patients' needs, but also considering technical limitations. The main information (patient- and setting-related; technology-related; and impact predictions) required by Horizon Scanning were addressed, presented in detail within the chapter, and summarized in the last subsection.

Chapter 3
Hospital services assessment and improvement

Hospital services are under the attention of researchers and healthcare professionals, especially for improving quality and processes. One of the most frequently used approaches within this context is lean management. However, systematic assessments of hospital services are not in use, probably due to the lack of specific data in the literature that does not allow systemic review of the state-of-the-art. Since hospital services represent an important area to manage from clinical engineering perspective, this part of the study was introduced within the overall study and it aimed to analyze two different services: the first one is the Clinical Engineering Service, since it is the *core* hospital service of clinical engineering, and the second one is the Central Sterilization Service, since it is closely related to operating theatre procedures, that represent the *core* activity of hospitals.

While Clinical Engineering Service was assessed through Multi-Criteria Decision Analysis [166], the Sterilization Service was firstly studied in terms of process improvement [167], applying lean techniques, and it was then assessed following HTA approach, integrated with Multi-Criteria Decision Analysis. The analyses were conducted in three different Italian hospitals.

3.1 Assessment of Clinical Engineering Services

The aim of this study was to assess a Clinical Engineering Service, considering particular needs and constraints of the specific hospital. Particularly, the study aimed to fulfill the need of re-engineering the Clinical Engineering Service in an Italian ASL (Local Health Authority) located in Sardinia, in accordance with the Italian regulations for healthcare.

Even if methods for processes redesigning in healthcare organizations are available in the literature, there are no recent evidences of their application in Clinical Engineering Services.

Among the multi-criteria techniques, in this work PAPRIKA was used, since, as already discussed in the first chapter, it is an easy-to-use and intuitive method for multi-criteria decision making, based on decision-makers' preferences.

We identified the decision makers' criteria to be fulfilled and four different preference levels for each criterion, as inputs of the method. Moreover four different scenarios were identified and, for each scenario and criterion, the decision makers selected the most suitable level.

3.1.1 Introduction

Accreditation process and compliance to mandatory standards are required worldwide by almost every hospital, in order to assess their level of performance and to implement ways to continuously improve. Even though the general purpose should be to adopt a unique set of requirements (such as the standards offered by Joint Commission International regarding Patient Safety, ISO series, or in the European Union the harmonization of law), the peculiarities of any single hospital and the requirements requested by a particular area must be considered.

This results in the need of identifying the best personalized scenario shaped on the specific healthcare organization.

In this study, we analyzed an Italian ASL placed in Sardinia in order to answer the need to redesign its Clinical Engineering Service (CES) in compliance with national and regional requirements for hospital accreditation.

Particularly, the minimum requirements defined in national (DPR 14.01.1997 no. 37) and regional (Sardinia, DGR 47/42 30.12.2010) regulations for hospital accreditation involve:

1. availability of procedures for managing biomedical technologies purchase, also based on their obsolescence in compliance with the technical regulation;
2. availability of a plan for preventive and corrective maintenances of biomedical technologies.

All the specific technological requirements are defined in checklists and questionnaires.

Furthermore, one more aspect to be considered concerns the actions to be undertaken for preventing adverse events due to malfunctions of medical devices, defined by the 9th Recommendation of the Healthcare Ministry in the Italian context.

In order to address the need of solving a decisional process aimed at the identification of the best solution among the alternatives, different evaluation techniques are available in the literature, as presented in the first chapter and detailed in following paragraph.

In the present paper the main research questions were as follow:

- Which is the best solution to be implemented in the ASL for redesigning the biomedical technologies management, in compliance with law requirements?
- What types of scenarios can we imagine?
- What is the best method to be chosen for finding the most suitable solution?

3.1.2 Material and methods

Description of the context

The Sardinian ASL investigated is composed by three hospitals for a total of 410 beds and 3,960 biomedical equipment.

The human resources of the Clinical Engineering Service are composed by:

- 1 Clinical Engineer;
- 1 Technician;
- 1 Administrative Assistant;
- 1 Assistant for warehouse activities and porterage.

The CES of the ASL is configured as a "mixed service": the internal clinical engineer is in charge of controlling the activities, and the assistance is provided by both an internal and two external technicians. Furthermore, some technologies are maintained by external companies.

Multi-criteria approach

Differently from the mono-criteria approach, the multi-criteria techniques use more than one evaluation criterion to choose the best solution. Indeed, it does not only maximize the result in terms of costs, but it aims to find the best overall solution, considering all the input variables, defined by the decision makers.

The mono-criteria approach is usually based on the economic and financial elements and it is more easy-to-use than the multi-criteria ones. Nevertheless, the exploitation of the single

economic and financial parameters does not always depict the actual perspective of the decision makers, and it does not allow considering qualitative factors.

On the other hand, the multi-criteria techniques address the actual need of decisional problems, often based on multi-objectives, multi-decision-makers, and multi-dimensions, through a matrix of both qualitative and quantitative data.

In this study, we adopted PAPRIKA, because, as detailed in the first chapter, differently from the other methods that measure decision makers' preferences through relative importance of each criterion, PAPRIKA quantifies the preferences through pairwise comparisons: this kind of comparisons are more natural and understandable, so that they can be considered more accurate and closer to the decision makers' preferences.

On the other hand, the limit of this method is represented by the exponential growth of the number of comparisons. In order to overcome this problem, we used the *1000 minds*, an online decision-making software developed by F. Ombler and P. Hansen [168], able to reduce the number of comparisons of PAPRIKA model.

PAPRIKA has been already used in the healthcare context, such as for healthcare technologies purchase prioritizing [169] [170], and for surgical patients' access prioritizing [171] [172].

Evaluation criteria and weights

Before creating the model, the identification and selection of criteria, decision model, levels of preferences together with the alternatives and attributes must be undertaken.

Initially, we identified four alternative scenarios that can be summarized as follow:

1. Alternative A1: Current situation at the ASL (described in "Description of the context" section);
2. Alternative A2: Outsourced management of Preventive Maintenance (PM), Testing (T) and Electrical Safety Verification (ESV) of all the biomedical technologies, except for the high technologies;
3. Alternative A3: Compliance to an Italian Ministerial program (CONSIP, SIGAE 4) that provides some base activities (i.e., maintenances, replacement parts supplying, Electrical Safety Verification, computerized management of the provided services, call-center, biomedical technologies disposal planning, internal technicians training) for the management of all the biomedical technologies, except for the high technologies;
4. Alternative A4: FULL RISK contract with a unique external company for all the biomedical technologies, except for the high technologies.

Subsequently, the decision makers identified, through a brainstorming session, six criteria of interest shown in Table 13.

Criteria	Description
C1	Dimensioning of human resources at CES
C2	Effects on the organization: work processes
C3	Supervisory capacity of the administration
C4	Quality of provided services
C5	Emergency and urgent problems resolution
C6	Annual costs the for biomedical technologies management

Table 13 – Criteria of interest

For each criterion, four levels of preference were defined, in terms of qualitative or quantitative parameters, depending on the specific criterion (Table 14). The levels of preference vary from L1 (option considered the best one) to L4 (option considered the worse one).

The weights of each criterion are automatically calculated by 1000 minds, based on the answers provided during the pairwise comparisons.

Criteria	Level	Description
C1	L1	2 engineers, > 3 biomedical technicians
	L2	1 engineer, 3 biomedical technicians
	L3	1 engineer, 2 biomedical technicians
	L4	1 engineer, 1 biomedical technician
C2	L1	A unique company in charge of all the activities management
	L2	A unique company in charge of MP and VSE
	L3	Different companies in charge of all the activities management
	L4	CES in charge of all the activities management
C3, C4	L1	Excellent
	L2	Good
	L3	Sufficient
	L4	Insufficient
C5	L1	Always guaranteed
	L2	Always guaranteed during working hours
	L3	Occasionally guaranteed during working hours
	L4	Never guaranteed
C6	L1	≤ 2 million €
	L2	> 2 million €, ≤ 2.25 million €
	L3	> 2.25 million €, ≤ 2.5 million €
	L4	> 2.5 million €

Table 14 – Levels of preferences for each Criterion

3.1.3 Results

Creation of the model

After the definition of the four alternatives (A1-A4), the six criteria (C1-C6) and the four levels of preference for each criterion (L1-L4), the four decision makers (the General Manager, the administrative Director, the healthcare Director and the CES Director) assigned a level of preference to each criterion of each alternative and they all agreed with the preferences shown in Table 15.

	C1	**C2**	**C3**	**C4**	**C5**	**C6**
A1	L4	L3	L2	L2	L3	L1
A2	L3	L2	L2	L2	L3	L2
A3	L1	L1	L4	L3	L1	L1
A4	L1	L1	L4	L3	L1	L3

Table 15 – Decision makers' levels of preferences

The best alternative scenario was then selected through the *1000minds* software, as it is explained in the following paragraph.

Choosing the best solution

The *1000minds* software provides the user with pairwise comparisons, so that they can either choose the preferred alternative or none.

Even if six criteria (C1-C6) and four preference levels, also called categories, (L1-L4) result in 4^6 = 4,096 possible alternatives (as described in the first chapter), the number of questions the decision makers' had to answer for letting *1000minds* software able to select the best solution, was equal to 372 (69% of 540 potential questions, identified by *1000minds*).

The weights of each criterion are assigned by the software, independently from the preferences expressed by the decision makers at the beginning (in Table 15), and in accordance to the user's preferences selected through the pairwise questions. The weights resulting from the comparisons are presented in the radar chart of Figure 8.

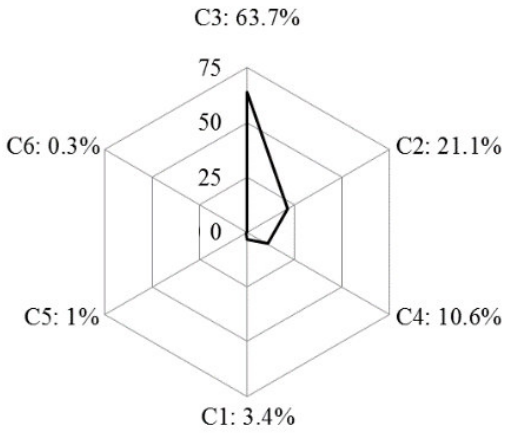

Figure 8 – Radar chart of criterion weights

The single score assigned to each of the six criteria is shown in Table 16.

Criteria	Level	Single Criterion Score (0-100)	Criteria	Level	Single Criterion Score (0-100)
C1	L1	0	C4	L1	0
	L2	33.3		L2	35.0
	L3	66.7		L3	67.5
	L4	100		L4	100
C2	L1	0	C5	L1	0
	L2	50.4		L2	33.3
	L3	83.3		L3	66.7
	L4	100		L4	100
C3	L1	0	C6	L1	0
	L2	33.3		L2	33.3
	L3	66.7		L3	66.7
	L4	100		L4	100

Table 16 – Single Criterion Score

Moreover, the "Marginal Rate of Substitution" (i.e., the rate at which the decision maker is ready to exchange an alternative for another one while maintaining the same level of utility) of the column criterion for the row criterion, has been calculated, and it is shown in Table 17.

	C3	C2	C4	C1	C5	C6
C3	1	3.0	6.0	19.0	61.8	247.0
C2	0.3	1	2.0	6.3	20.5	82.0
C4	0.2	0.5	1	3.2	10.3	41.0
C1	0.1	0.2	0.3	1	3.3	13.0
C5	0.0	0.0	0.1	0.3	1	4.0
C6	0.0	0.0	0.0	0.1	0.3	1

Table 17 – Relative importance of criteria

Finally, the fully ranking of all the four alternatives was found by the software at 460th answer (85% of 540 potential questions).

3.1.4 Discussion and conclusions

The results show that the Alternative A2 (weighting 68.8%) represents the best solution for the ASL, followed by the Alternative A1 (current situation, 60.8%) and the Alternatives A3 and A4 (both 28.2%). Indeed, the A2 scenario represents the best compromise between the levels identified by decision makers for each scenario and their preferences selected during the assessment.

Furthermore, the most important aspect to be considered is the supervisory capacity of the administration (Figure 8). This result underlines the policy makers' awareness of the importance of implementing a structured policy, closely related to quality improvement of service and long-term cost saving. This fact is confirmed by the high weights assigned to C2 ("Effects on the organization: work processes") and C4 ("Quality of provided services") criteria. It represents a strong long-term perspective, in which it is better to make high investment at the beginning, in order to achieve more durable and high-quality results.

The application of the PAPRIKA method for redesigning the Clinical Engineering Service in compliance with national and regional requirements for hospital accreditation can be considered successful.

Indeed, it has been possible to identify the best scenario (A2), according to the most important criteria selected by decision makers', and underline the path to be followed by the Organization, defined by the resulting criteria scores.

The selected Scenario allows the CES to adopt, on a case-by-case basis, the solution that guarantees the best quality and the patient safety. It is also the Scenario with the highest level of

C3 ("Supervisory capacity of the administration") and C4 ("Quality of provided services"), considered among the most important aspects by decision makers.

On the other hand, through the adoption of the Alternative 2, the emergency and urgent resolution can be improved by applying the a priori identification of the equipment classes most susceptible to breakdown, in order to make replacement devices available in case of need.

3.2 Process improvement of Sterilization Services

In line with the overall study, that aims to find methods and approaches for improving the healthcare domain in different areas, this section is specifically dedicated to the process for managing surgical tools, with particular attention to Sterilization Service. The study assesses the current sterilization service of an Italian hospital, proposing a reorganization of the current solution through different techniques currently used within process management, in order to improve the sterilization service.

Particularly, the study exploits lean management that constitutes an emerging approach in the healthcare context, in order to increase quality of care and reduce costs. Nevertheless, literature shows the lack of a standardized method for applying lean techniques, especially in healthcare, due to the complexity of the involved processes.

Specifically, this section proposes an innovative method for standardizing the lean management approach in healthcare, in order to reduce wastes in hospitals. The integration of different techniques (i.e., IDEF0 and GQM), generally used in process management is proposed, in order to let the overall method reproducible and repeatable. The application and feasibility of the method has been studied in an Italian hospital, in the specific context of Sterilization Service, since it subtends some *core* activities within hospitals.

3.2.1 Introduction

Lean principles have been worldwide used in the service industries, in order to reduce wastes (*muda*), improve processes, increase quality of services, and decrease costs. Lean management was introduced for the first time in the manufacturing sector (Toyota) [173], and it has been successful in waste reduction of the production process, delivering high-quality products. Its success has been proved in the automotive and electronic fields [174], too.

In the last decade, lean has been applied also in healthcare services that significantly need of improvement in the domains of safety, effectiveness, timeliness, and appropriateness of care services [175], representing one of the most considerable trends in service industry [176]. Moreover, the improvement of care processes, which represents another direct consequence of the lean management implementation, produces reduction of costs and the consequent resources reallocation.

Several worldwide healthcare organizations are currently using lean approach. Nevertheless, a standardized method has not been yet defined, coherently with the lean

management historical evolution (initial lack of written procedures for describing the method) [177].

Furthermore, the implementation of lean as a systematic approach in hospitals is not easy, due to the complexity of the care processes, the stakeholders involved [178], the specific needs and different cultures [179] of organizations. Moreover, one of the most challenging goals the healthcare systems have to deal with is the rapid growing and acquisition of new technologies [180]: people involved in the processes have to be continuously trained, and Standard Operating Procedures must be frequently updated. Another crucial aspect to be considered is the resistance of operators to management changes, anytime a new process or technology is introduced.

For these reasons, hospital must be considered as a complex dynamic environment, and the introduction of a systematic approach must be studied and assessed carefully.

In order to add value to an organization, it is essential to identify and eliminate waste, starting from the analysis of processes. The lean tool used for this purpose is the Value Stream Map (VSM), a method for analyzing the current state (Current Stream Map) and designing a future state of a process (Future Stream Map). Nevertheless, the literature shows that some of the metrics used in the VSM lack of a unique definition, especially in the healthcare context. This makes difficult to compare different studies in the literature, and to evaluate clearly the actual improvements of the organization following the lean techniques application. Indeed, the goal of a metric should be obtaining objective, reproducible and quantifiable measurements, but this goal is not always reached, due to differences in the definitions of VSM metrics available in the literature.

In order to measure properties of software and its specifications, in the computer science context many software metrics (e.g., Halstead Complexity, DSQI, Robert Cecil Martin's software package metrics, Goal Question Metric) have been used. Particularly, Goal Question Metric (GQM) [181] is used to gather the measurement data and drive decision making and improvements, providing a support for identifying metrics starting from the definition of goals.

On the other hand, different functional modeling methods (e.g., function block diagram, HIPO and IPO, N2 Chart, IDEF0) are available in system engineering and they can be used as a support to the Value Stream Mapping. Particularly, IDEF0 is sometimes used as a support of lean management, since it allows mapping and analyzing complex interactions of a system [182].

In this section, a standardized method, based on lean principles, supported by IDEF0 and GQM that can be used in any manufacturing and healthcare context is presented. Moreover, the problem related to the lack of mathematical formula for defining some metrics used in the VSM is faced and a solution is proposed.

3.2.2 Material and methods

Lean Thinking and Lean wastes

The main purpose of lean management is to create value for the end customer, through the elimination of wastes. Its philosophy derives mostly from the Toyota Production System (TPS), and it is focused on reduction of the original Toyota seven wastes (briefly described in Table 18) to improve overall customer value. Some other wastes have been added later on from other researchers, even though they have not been universally accepted [183].

The Value Stream Map is the lean management tool for mapping the actions of the actors involved in a process. It employs standard symbols to represent items and processes, and key metrics are associated with each phase of the described process.

Moreover, different tools are currently used and integrated at TPS operational level, such as Total Quality Management for assessing quality, Theory of Constraints for identifying constraints and restructure the rest of the organization around it, Six Sigma (6σ) and Statistical Process Control for assessing the variability of a process. Even though it is not yet a common and shared approach, a recent study [184], proposed the application of lean systems approaches to health technology assessment, in order to create real incentives for innovation and value creation.

Type of waste	Brief Description	Example in healthcare context
Defects	Time spent doing something incorrectly, inspecting for errors, or fixing errors	Surgical case cart missing an item
Overproduction	Doing more than what is needed by the customer or doing it sooner than needed	Performing unnecessary diagnostic procedures
Transportation	Unnecessary movement of the product in a system (patients, specimens, materials)	Poor layout, such as the sterilization service being located a long distance from operating theatre
Waiting	Waiting for the next event to occur or next work activity	Patient waiting for an appointment
Inventory	Excess inventory cost through financial costs, storage and movement costs, wastage	Expired supplies that must be disposed of, such as out-of-date medications
Motion	Unnecessary movement by employees in the system	Lab employees walking miles per day due to poor layout
Overprocessing	Doing work that is not valued by costumers, or caused by definitions of quality that are not aligned with patient needs	Time/date stamps put onto forms, but the data are never used

Table 18 – Types of waste (Modified by [185])

IDEF0

The IDEF0, a part of the IDEF family of modeling languages of software engineering, is a function modeling methodology that provides a representation of a process, combing texts, diagrams and graphic, detailing information about the input and output of an activity, how that activity is controlled, and the involved resources and mechanisms. It results in a hierarchical description that shows the links among the activities. The overall description of the process can be specified according to the level of the description needed by the organization, or the complexity of the process itself.

GQM

The Goal Question Metric is a measurement system that can be divided into three levels:

- Goal (Conceptual level): it defines the main purposes of a work to be measured;
- Question (Operational level): it defines a set of questions useful for achieving the goals;
- Metric (Quantitative level): it defines a set of metrics for answering the questions in a measurable way.

The overall GQM diagram is shown in Figure 9.

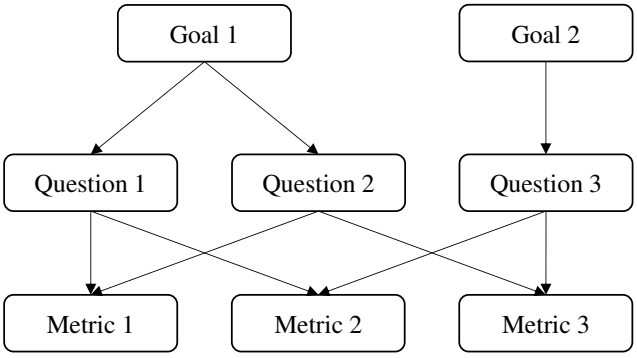

Figure 9 – GQM overall diagram

3.2.3 Standardizing lean approach

The representation of lean approach standardization, proposed in this study, is presented in Figure 10. In order to improve an activity in accordance with lean-thinking, an analysis of the overall process must be addressed. A team-leader must be identified for getting guidance and suggestions on directions. The team leader should have the capability to work in a multi-disciplinary team, for interacting with people with different backgrounds. She/he should also

have an engineering background, for providing systematic and precise instructions to the team, in order to design and describe the process. Moreover, she/he should know and understand the healthcare environment as well as the most common related issues. This is the reason why clinical engineering has also being involved in this field.

IDEF0 can be used to describe the process and identify the most problematic areas and the inter-relations among different activities. This phase must be addressed with the contribution provided by the actors involved in the process, who can describe the actual problems and, consequently, the real improvement areas. The team-leader must follow personally the process, in order to gain an external perspective of the main problems associated.

For identifying measurable metrics, the support of GQM can be valuable. Since the main goal of the lean-management is to reduce wastes, the reduction of *mudas* selected by the organization can be set as the Goals in the GQM. Questions must be found in order to reduce the wastes identified in a process, and measurable metrics (described through mathematical formula) must be defined.

The Current Stream Map, required by lean philosophy, can be designed by summarizing the most important phases of the process to be improved and selecting the metrics, identified through GQM and included in the data box. Through the analysis of the collected data, improvement solutions based on lean-techniques (e.g., Work Standardization, Poka-Yoke, Kanban, Spaghetti Diagram) can be implemented, and the Future Stream Map can be designed.

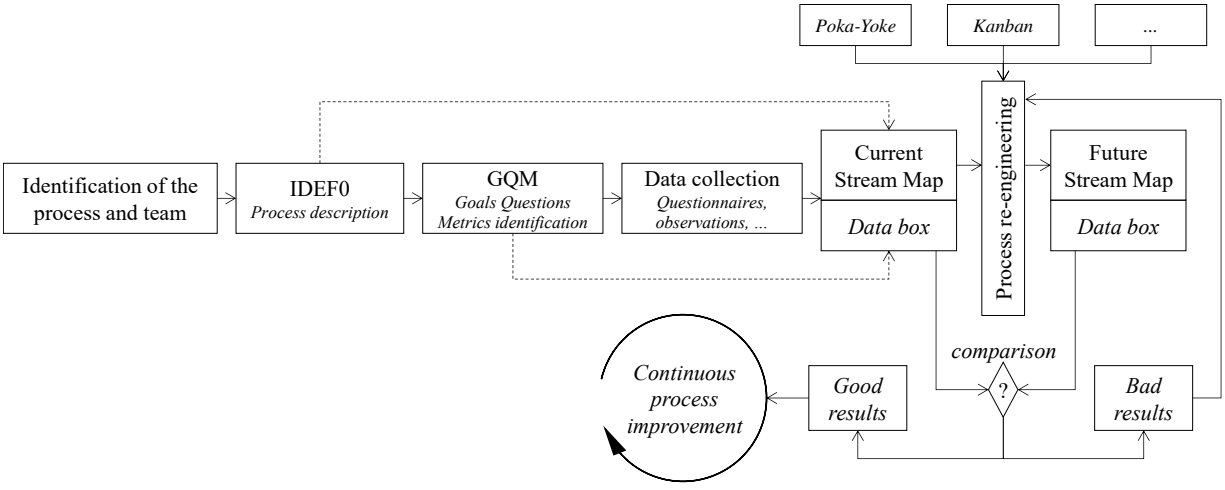

Figure 10 – Diagram block describing the proposed method for standardizing lean approach

Through the comparison between the metrics of the Current and the Future Stream Maps, the improvements of the process can be monitored during the time.

Case study

In order to evaluate the described method, it was tested in the Operating Theater and Sterilization Service of the Italian Hospital F. Miulli. Particularly, the surgical tools process was studied. The criteria used for selecting this process among the others were related to the importance of the activity in a core process, the arising attention on the matter by the international patient safety organizations (e.g., JCI), and the complaints related to the surgical tools the top managers have been received from clinicians and nurses working in the Operating Theater. Preliminary, informal interviews were made with the actors involved in the process, and the professionals who wanted to give a support to improve the process were selected as part of the team. The survey was designed as in Figure 11.

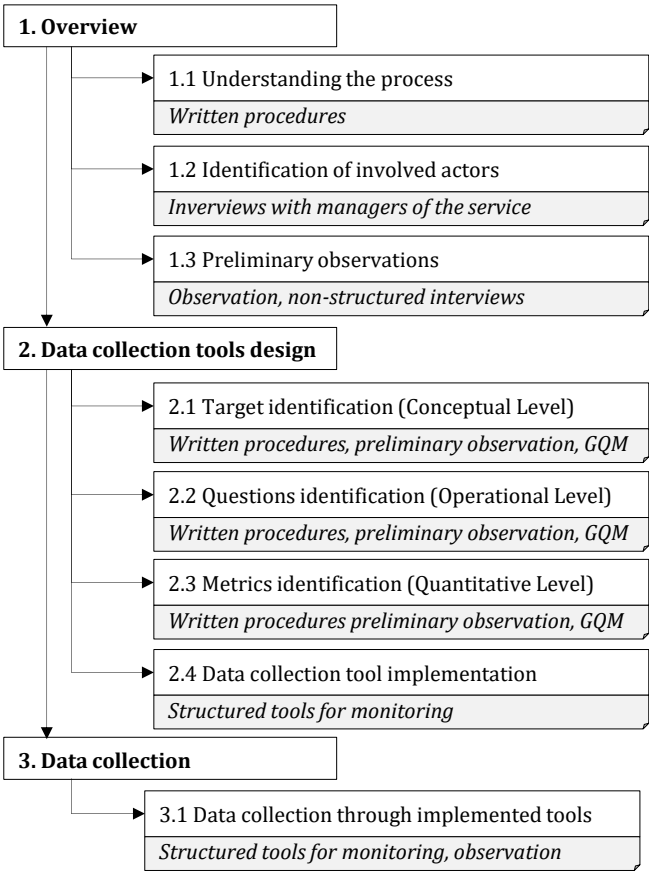

Figure 11 – Survey set-up representation

The surgical tools process was described, both for the activities performed in operating theatre and central sterile services department, with IDEF0 (Figure 12 and Figure 13), and detailed descriptions were made with respect to the most precarious activities (i.e., methodology for preparing the surgical tools containers, number and typology of surgical tools prepared before surgical operations, nonconformities). Particularly, "nonconformities" refer to defects that deviate from standards defined by quality regulations.

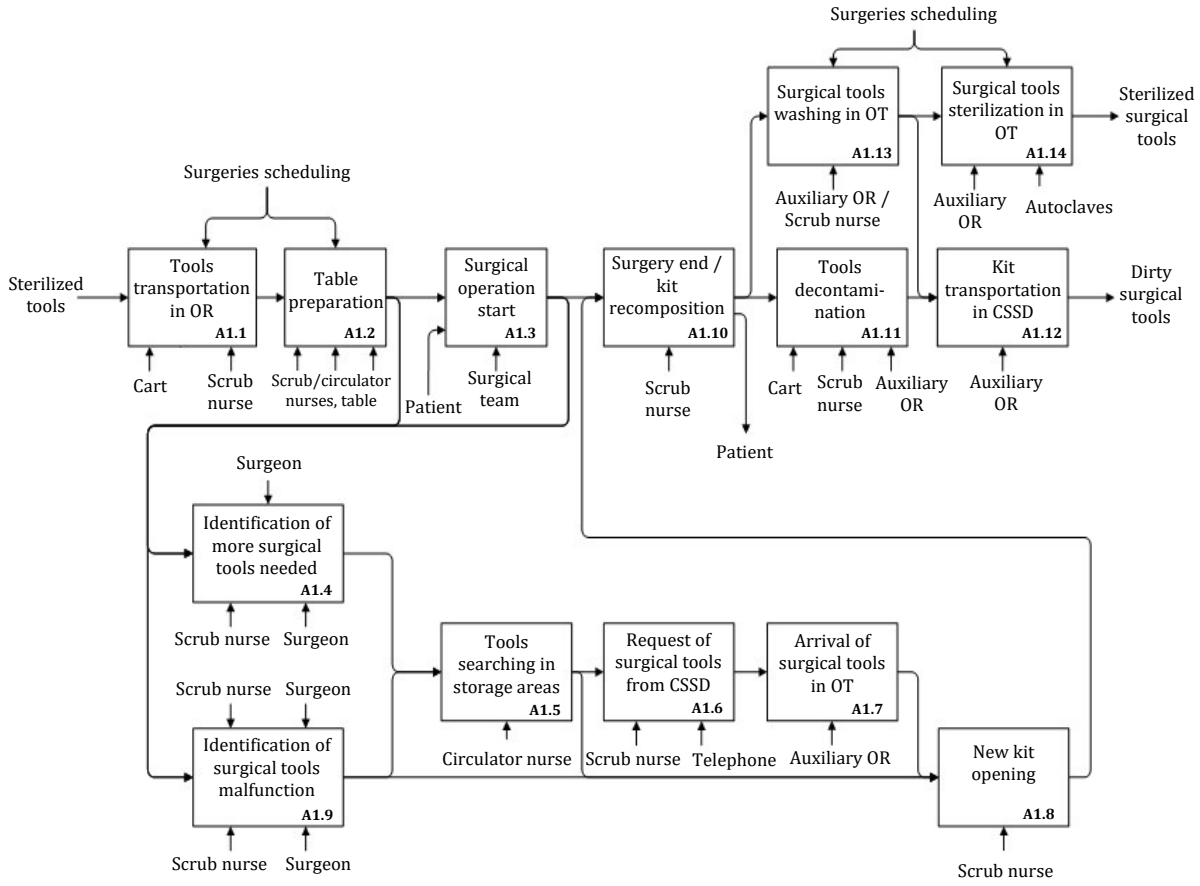

Figure 12 – Representation through IDEF0 of surgical instruments process within the Operating Theatre (OT: Operating Theatre, OR: Operating Room)

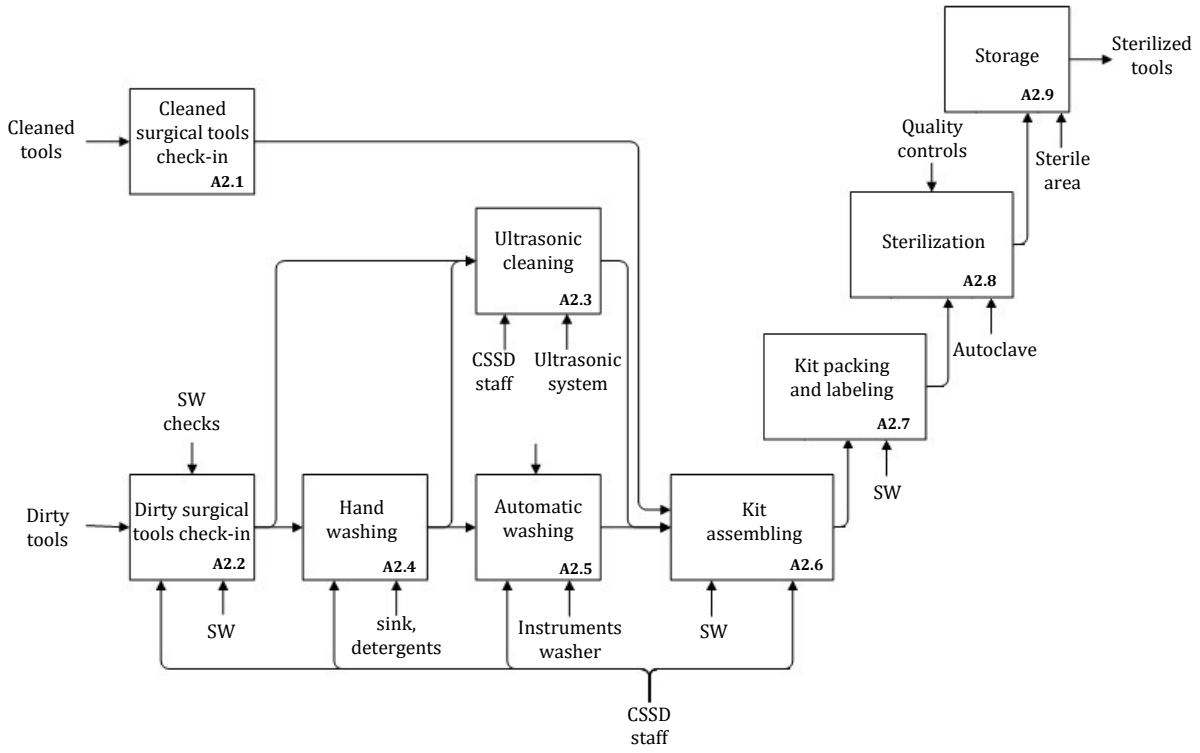

Figure 13 – Representation through IDEF0 of surgical instruments process within the Central Sterile Supply Department (CSSD: Central Sterile Supply Department, SW: Itineris, Software currently in use)

The reduction of the seven *muda* (aggregated in 6 goals in Figure 14), was set as goals in the GQM. As detailed in Figure 14, fifteen questions were identified and seventeen metrics were defined.

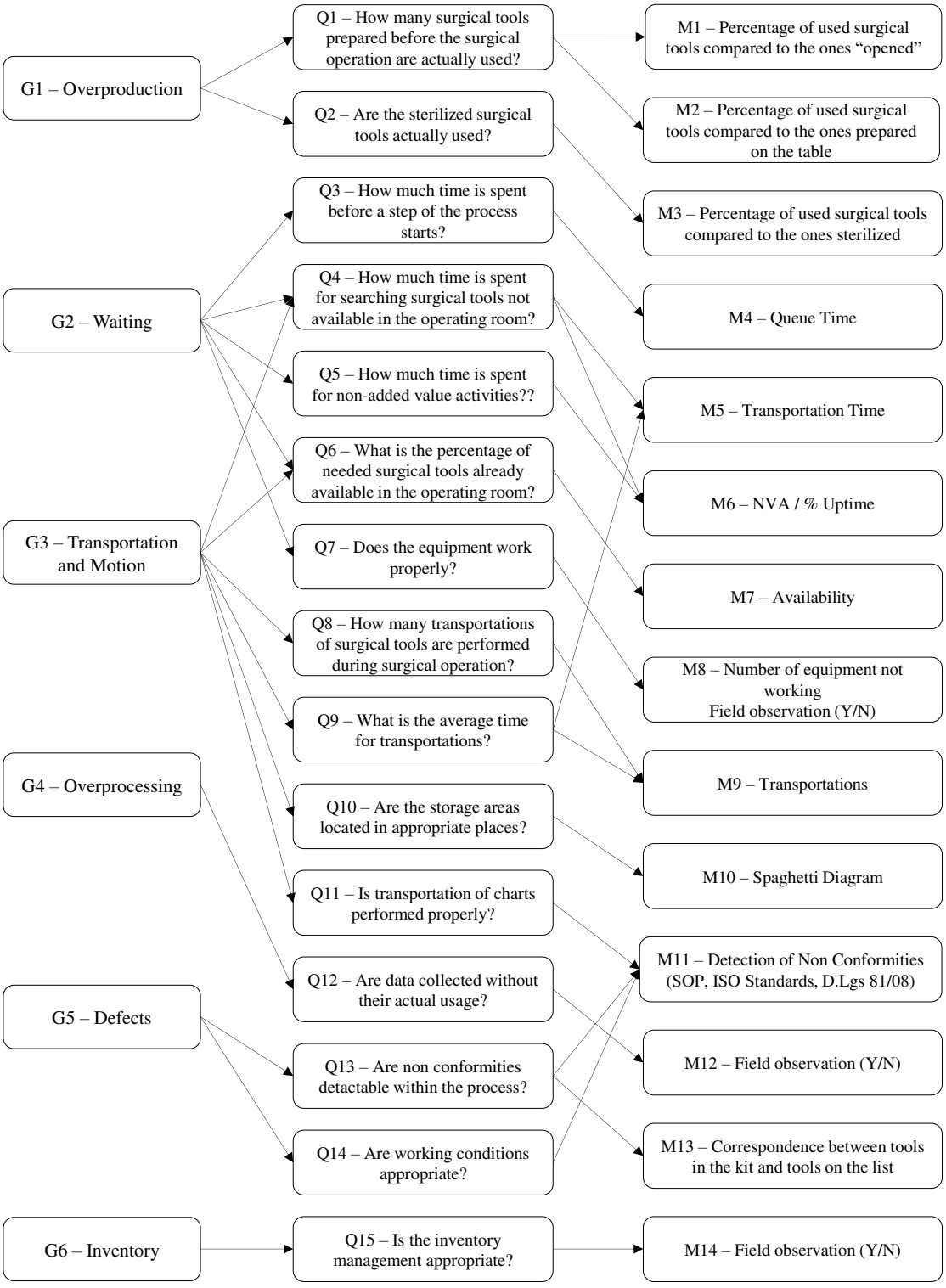

Figure 14 – Description of Goals (wastes to be reduced), Questions and Metrics identified for improving the process

For each metric included in the study, a description together with mathematical formulas was provided (Table 19, related to Operating Theatre and Table 20 related to Central Sterile Services Department).

Particularly, regarding operating theatre activities, s is defined as s-th transportation of the S total transportations, where $0 \leq s \leq S$, t_i and t_f are initial and final time respectively of each step of the process, where:

$$t_0 < sterile\ instrument\ table\ preparation < t_1$$
$$t_2 < sterile\ instrument\ usage < t_3$$
$$t_4 < positioning\ used\ surgical\ instrument\ on\ the\ cart < t_5$$
$$t_6 < transportation\ to\ Sterilization\ Service < t_7$$

Metric for VSM	Tag	Definition	Formula
Observation	N	Total number of observations	
Cycle Time	CT	Cycle Time: average time for completing an activity of the process, being N the total number of observations, t_{in} and t_{fn} the initial and final time of the n-th activity, respectively	$CT = \frac{1}{N}\sum_{n=1}^{N}(t_{fn} - t_{in})$
Transportation	$\bar{S}$	Average number of transportations within any single step of the process, due to the necessity of finding and moving surgical tools not available in the operating room	$\bar{S} = \frac{1}{N}\sum_{n=1}^{N} S_n$
Transportation Time	$\bar{t}_s$	Average time of the s-th transportations for finding and moving needed surgical tools in the operating room	$\bar{t}_s = \frac{1}{S}\sum_{s=1}^{S} t_s$
NVA Time	NVA	Not Value Added: time spent in avoidable tasks (e.g., avoidable transports made by the operators looking for needed surgical tools not available in the Operating Rooms) S is the total number of transportations, and $\bar{t}_s$ is the average time of transportations	$NVA = \frac{S \cdot \bar{t}_s}{N}$
VA Time	VA	Value Added: time spent for add-value tasks of the process, defined as difference between the Cycle Time and the Non-Value Added time	$VA = CT - NVA$
Uptime %		Percentage of the process (or part of the process) that brings only added value	$\%\ Uptime = \frac{VA}{CT} \cdot 100$
OST	--	Opened Surgical Tools: number of "opened" (not anymore sterile) surgical tools, at the end of the process	
UST	--	Used Surgical Tools: number of surgical tools "used" in a specific phase of the process (e.g., number surgical tools positioned on the surgical table within the first phase, number of surgical tools used for surgical operation within the second phased, etc.)	
Utilization	--	Percentage of surgical tools used in a specific phase of the process	$\%\ Utilization = \frac{UST}{OST} \cdot 100$

Metric for VSM	Tag	Definition	Formula
NC	--	Average of Non Conformities detected in a specific phase of the process	$\% NC = \frac{N_{with\ NC}}{N} \cdot 100$
Availability	--	Prompt availability of surgical tools needed for completing a specific phase of the process (e.g., availability of surgical case cart (SC) or surgical kit (SK) directly in the operating room (OR) within the first phase, availability of transportation cart for moving used surgical tools to sterilization service within the third phase)	$\% Availability = \frac{\sum(SC+SK)_{in\ OR}}{\sum(SC+SK)_{needed}} \cdot 100$

Table 19 – Description of the Metrics used in the Value Stream Map of surgical tools in the Operating Theatre

Regarding Sterilization Service activities, k is defined as k-th surgical kit studied during observation and data collection, where $0 \leq k \leq K$, t_i and t_f are initial and final time respectively of each step of the process, where:

$$t_0 < check - in < t_1$$
$$t_2 < hand\ washing < t_3$$
$$t_4 < automatic\ washing < t_5$$
$$t_6 < assembling\ and\ packaging < t_7$$
$$t_8 < sterilization < t_9$$

Metric for VSM	Tag	Definition	Formula
Kit	K	Total number of processed surgical kit in any single phase	
ST	ST	Total number of surgical tools available (not necessarily used) in any single phase)	
PST	PST	Processed Surgical Tools: number of surgical tools processes in any single phase	
CT/kit	CT_K	Kit Cycle Time: average time for completing a single phase of the process, considering the kits processed in the Sterilization Service	$CT_K = \frac{1}{K}\sum_{k=1}^{K}(t_{fk} - t_{ik})$
CT/PST	CT_{PST}	Single surgical tool Cycle Time: average time for completing a phase of the process, considering the total surgical tools processed within the single phase	$CT_{PST} = \frac{1}{PST}\sum_{k=1}^{K}(t_{fk} - t_{ik})$
Check ST	% Check	Percentage of kits where correspondence between intended and actual surgical tools was checked (either if output was positive or negative)	
MST		Missed Surgical Tools: average number of missed surgical tools in any single kit where correspondence was checked	

Table 20 – Description of the Metrics used in the Value Stream Map of surgical tools in the Central Sterile Supply Department

Data related to twenty-three observations, one for each surgical operation, were collected within the operating theatre. Data related to thirty-nine kits and 1,937 surgical tools were collected within the sterilization service.

The Current Stream Maps were designed for both the activities managed in the operating theatre (Figure 15) and the sterilization service (Figure 16), through the identification of the most important process activities and collected data were inserted into the data boxes, as discussed in the next paragraph.

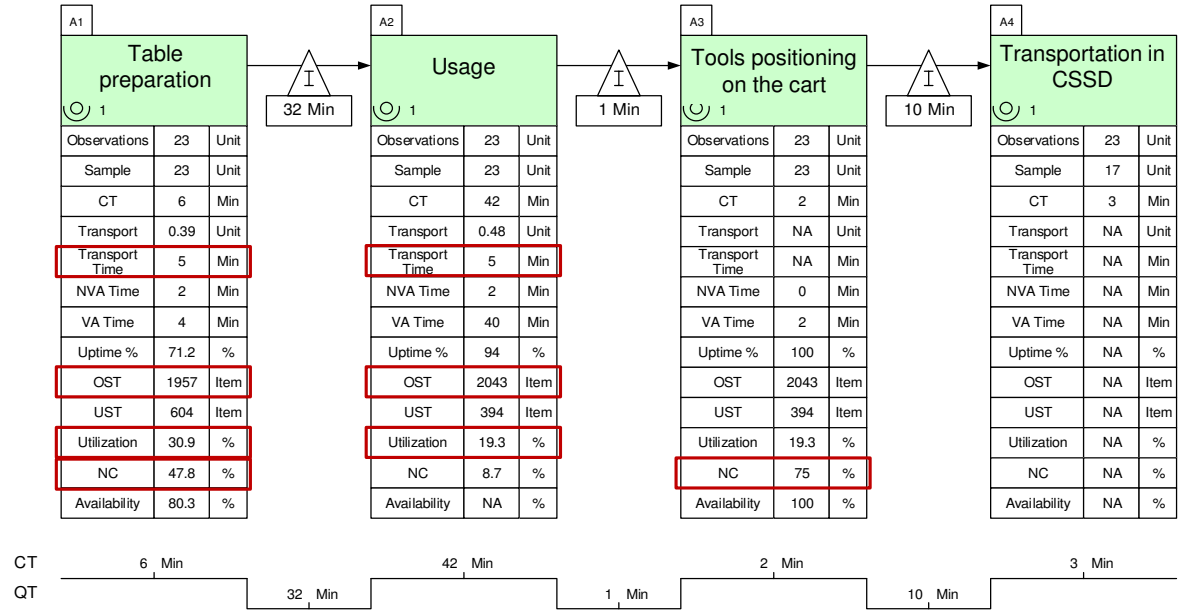

Figure 15 – Current Stream Map of surgical tools in the Operating Theatre

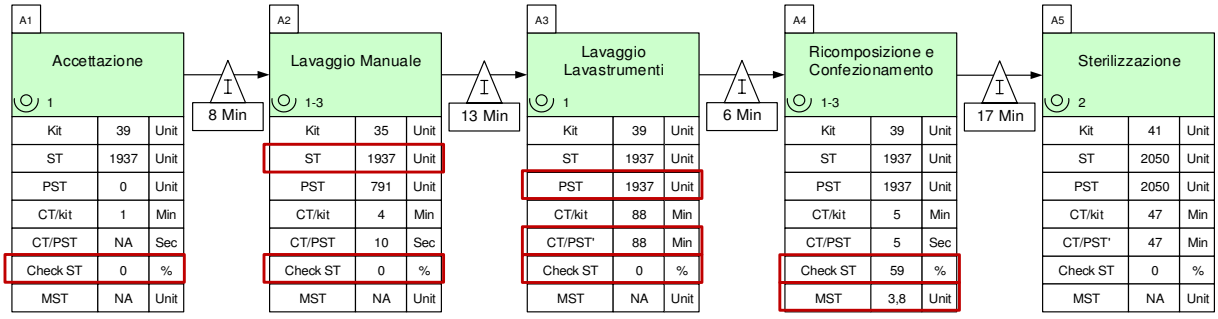

Figure 16 – Current Stream Map of surgical tools in the Central Sterile Supply Department

3.2.4 Discussion and conclusions

The analysis of collected data allowed the identification of the critical points of the process. Particularly, regarding activities in operating theatre, according to the metrics initially defined, critical points, as showed in Figure 15, were related to Utilization = 30.9 % at the Stage 1 and Stage 2 of the process; transportation time $\bar{t}_s$=5 minutes in Stage 1 and Stage 2 of the process; nonconformities = 47.8% and 75% during Stage 1 and Stage 3 of the process, respectively.

Regarding sterilization department, the critical points, as showed in Figure 16, were mainly related to the lack of surgical tools checking during any phases of the process; the surgical tools over-processed during hand and automatic washing, since all surgical tools were completely processed even though they were not utilized during surgical procedures; and missed surgical tools not inserted in their package/case before sterilization.

The process has been reviewed, the Future Stream Map was designed, the new process was simulated and the economic saving was calculated (see Table 21).

Through some improvement activities, such as the inventory of surgical tools, and new definition of tools in the case/package, it is possible to increase the availability of the surgical tools, reduce the number of tools to be transported and to be processed by the Central Sterile Supply Department. From an economical perspective, an estimated hospital saving of 242,404 € (presented in Table 21) could be produced applying these improvements.

Particularly, the redefinition of the storage areas and the application of both 5S (a lean method for organizing a work space for efficiency and effectiveness [186]) and Visual Management (a lean visual control method for increasing the efficiency and effectiveness of a process by making the steps in that process more visible [187]) may reduce the time spent for looking for the needed surgical tools (saving estimated to be 13,000 €).

Furthermore, Cycle Time would be reduced of the 33% during the preparation of surgical tools, since less surgical tools would be positioned on surgical tools table, and the utilization of tools would increase of 70% (considering the availability of at least 30% tools to be used in case of emergency) and 45% (considering that surgical tools actually used would be, anyway, less than the ones prepared within the "base-configuration" that excludes emergency situations) during the preparation of surgical case cart and the utilization phases, respectively.

Finally, nonconformities would be reduced of 47% and 75% during the preparation of the surgical tools cart and the positioning of the tools on the cart, respectively.

Activity	Unit cost	Consequences	Annual saving
Census and redefinition of surgical kit	5,500 €	Increased surgical tools availability	13,088 €
		Less surgical tools to be processed within Sterilization Service	207,333 €
		Elimination of washing activities within operating theatre	9,000 €
Redefinition of surgical tools storage points within operating theatre and application of 5S and Visual Management	280 €	Reduction of time spent for looking for surgical tools	12,983 €
Total	**5,780 €**		**242,404 €**

Table 21 – Estimation of cost savings thanks to the implementation of the suggested activities aimed at reorganizing the process of surgical tools

The application of the methodology was a useful support for the study and application of lean management techniques. The integration of IDEF0 and GQM facilitated the description of the process and identification of the metrics of interest. Indeed, structured metrics were provided and this makes possible the comparison between different studies. The proposed approach is versatile and it can be applied in any process or service, not only referred to the healthcare domain. Good results were achieved in terms of process efficiency, cost, cycle time, and nonconformity reduction.

3.3 HTA applied to hospital services through MCDA

As already discussed, several authors acknowledged the complexities inherent in conducting HTA rapid reviews, suggesting that it is difficult to accomplish the triad of responsiveness to short timeframes, scientific rigor, and transparency in a manner consistently acceptable to all stakeholders [188]. However, despite these challenges, some HTA organizations reported producing a considerable number of rapid reviews [106]. "Short HTA" are then considered acceptable by both decision makers and scientific literature. Moreover, in those contexts where it is not easy to find comparative studies, due to lack of evidence in the literature, this is a useful starting point for defining structured approaches, based on scientific rigor, short timeframes, and usefulness from decision makers perspective.

Particularly, hospital services should be assessed as well as other technologies are currently assessed through HTA, since they represent a crucial point for hospital and patients in terms of costs, efficiency, quality, and risk management.

This section aims to apply the HTA approach to hospital services, considering the latter as technology assets of considerable importance within the healthcare domain. The study was conducted in within the Central Sterile Services Department (CSSD) of an Italian hospital.

3.3.1 Introduction

Perceived quality in healthcare is closely related to health system performances. Different frameworks for monitoring performance indicators are available in the literature and currently used in healthcare facilities, also driven by international organization for quality and patient safety (e.g., JCI) and quality regulations and standards. Before monitoring ongoing results in order to evaluate trends of healthcare facilities, it is important to gain insight into determinants that may facilitate or impede the introduction of innovations [189], and to carefully assess new processes, services or, more generally, technologies to be adopted in order to improve healthcare provision. As already discussed, HTA does not have a precise and standard definition, and its actual contents may vary in different application contexts [190]. Although the main steps of HTA have been identified, as reported by [191], the dimensions (or "domains" as defined by EUnetHTA) included in practical assessments often differ. Indeed, dimensions included in HTA are slightly different among national and international societies. For example, the Health Technology Assessment international (HTAi) society focuses on clinical, economic, organizational, social, legal and ethical issues; the WHO focuses on social, economic,

organizational and ethical issues; the Italian Agency for Regional Health Services (Age.Na.S.) focuses on effectiveness, safety, costs, and social-operational issues.

The reason behind the absence of a harmonized definition may be related to different reasons, such as the stakeholders commissioning the assessment (macro-decision makers, e.g., governments and health ministries; meso-decision makers, e.g., hospitals and community health agencies; micro-decision makers, e.g., clinicians, patients [192]), the peculiarities of specific contexts and the peculiarities of health technologies. This last aspect deserves particular attention, as the term "Health technology" subsumes a wide range of technologies. In fact, health technology has been defined as the "application of organized knowledge and skills in the form of devices, medicines, vaccines, procedures and systems developed to solve a health problem and improve quality of lives" [193], or "drugs, devices, and medical and surgical procedures used in medical care, and the organizational and supportive systems within which such care is provided" [194]. Scientific papers and national guidelines on HTA [195] mainly confine their attention to those technologies that directly involve patients (such as medicines, medical devices, and surgical procedures). Along the same lines, available HTA reports are primarily focused on the direct (potential) effects of the technology on patients, who are considered key stakeholders in the decision making process [196]. The interest toward this kind of technologies may be also induced by standards and regulations mandatorily required for both medical devices and drugs before their admission into the market, as well as the growing consideration of the best practices in patient pathways. Conversely, hospital services have received little attention in the HTA literature, even if, in many cases, they have non-negligible indirect impacts on patients. Such considerations have been remarked in recent studies; in particular, the recent Clinical Engineering Handbook has introduced the concept of "health technology assets, such as medical devices and supplies; physical infrastructure, such as health buildings and associated services and utilities; and logistics support and information systems" [8].

Consequently, even if hospital services can be included among the health technologies within HTA, its actual application might be problematic due to the lack of information of state-of-the-art scientific findings, the difficulty to compare the available data and to devise standard methods that are capable to consider both the best practices and the peculiarities of each context.

However, some of the still open challenges of the application of MCDA in HTA regard the identification and definition of the criteria to include in the assessment, and how to select criteria that are worldwide recognized as important. This problem is even more difficult for health technology assets, as hospital services, since the available literature is lacking. Some studies that investigated solutions to the reduction of expenditure and process improvement are

available in the literature. Particularly, MCDA has been used for assessing hospital services, such as Clinical Engineering Service [166] and Central Sterile Services Department (CSSD) [197]. Those studies emphasize the practical difficulties that are met in the case of complex services, whose assessment require to consider technical, economic and organizational aspects. A case in point is the assessment of different solutions for the CSSD, which constitutes a valid test case for MCDA application.

CSSD is defined as a technical support unit, whose purpose is to provide appropriately-processed medical-hospital articles, thus providing conditions for direct attendance and health care provision for ill and healthy individuals [198]. Indeed, CSSD plays a crucial role in hospital settings, since it provides tools and medical devices that must be properly sterilized, assuring the appropriate quality of medical care [199]. Actually, besides adverse events for patients, defects in sterilization can lead to heavy economic burden [200].

CSSDs can be considered as hybrid systems, since they include not only products (e.g., medical device, supplies), but also structures, work processes, and organizational aspects that have to be carefully assessed and monitored for assuring good quality of service. CSSD must comply with national and international standards, as well as quality and safety requirements defined at different levels and that can depend on the specific health care system. However, hospitals are usually allowed to implement different organizational configurations of the service, internal, outsourced or mixed [197], according to their strategic goals, preferences, external constraints and opportunities.

On the grounds of the previous considerations, the present study aims to answer the following research question: is it possible to find a generalized method for assessing hospital services, integrating international experts' know-how and specific needs at a local level? In order to address this question, an assessment methodology, based on the concepts of HTA and supported by an MCDA method, was devised and applied to an Italian case study.

3.3.2 Methodology

The proposed methodology is performed in several steps, some innovative, which aim to involve both international and national panels of experienced professionals, and other that represent a combination of some of the available paths described in the literature concerning HTA and MCDA (e.g., [201], [202], [203]).

A workflow of the assessment process is shown in Figure 17 and its main steps are summarized in the following numbered list:

1. Identification of the decision goal
2. Identification of the alternative technology assets (alternative services)
3. Decomposition of the decision objective into evaluation dimensions
4. Definition of the criteria (such as properties, measures of performance, etc.) of interest for each dimension
5. Selection of the most important criteria for each dimension, which will be used for the assessment (international level)
6. Assessment of the alternative services on the selected criteria (local level)
7. Calculation of group judgments and overall performance of the alternatives (local level).

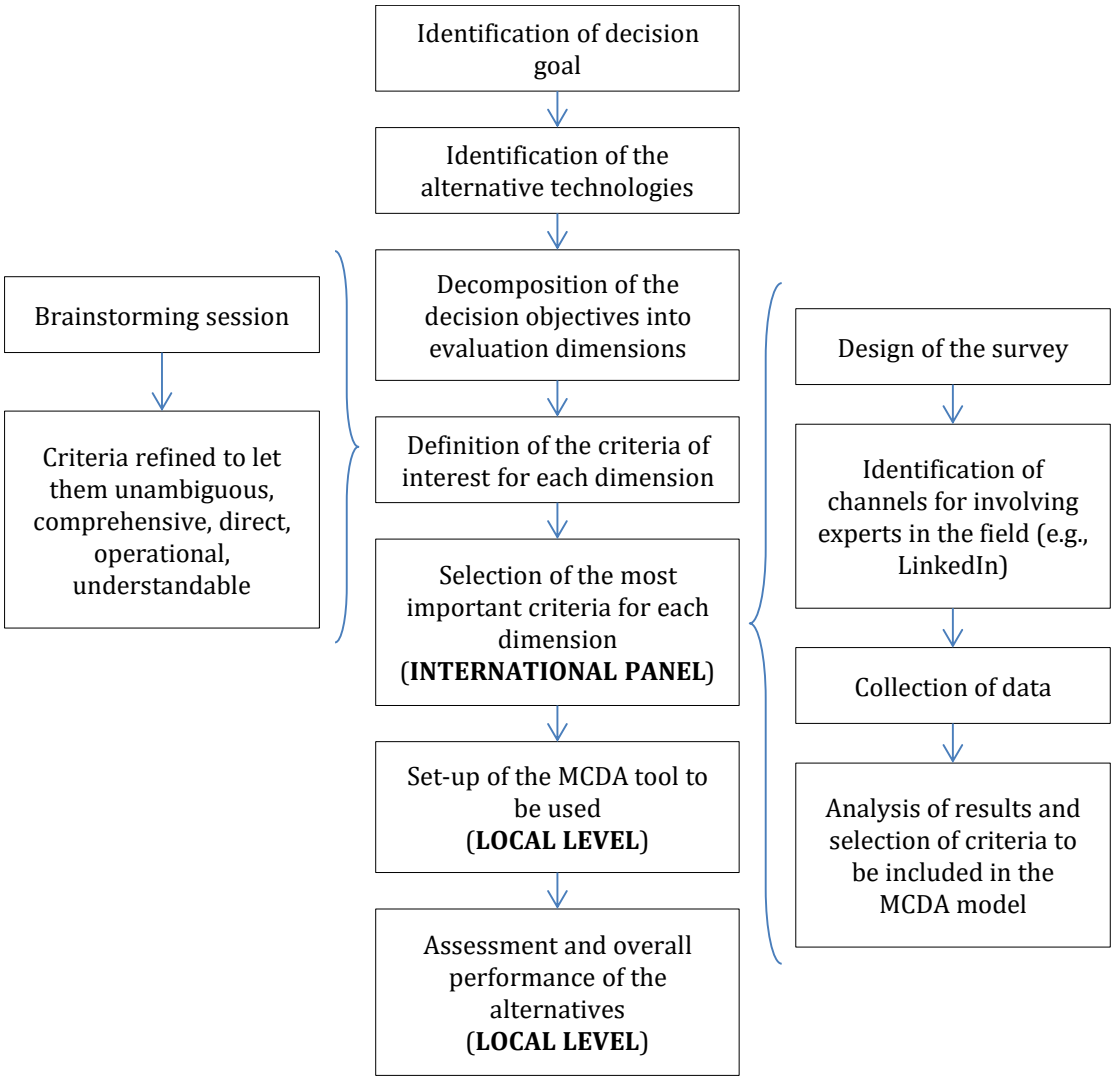

Figure 17 – Workflow of the assessment process

The method was applied to the Italian local health authority of Matera ("ASM"), in Basilicata Region. The ASM comprises five hospitals. Among these, three hospitals perform surgical activities, for a total of 392 ordinary beds, 90 Day Hospital beds, 15 operating rooms, 13,000 surgical operations in 2015. The current sterilization service is mixed, since some of the activities are outsourced to external companies. However, the ASM owns proprietary systems, technologies and surgical tools.

A detailed description of the steps of the methodology is provided below.

First of all (step 1) it is necessary to identify the technology to be assessed. In healthcare services, the technology asset may be a hospital service that has to be renewed due to different reasons, such as indirect hazardous consequences related to the service (e.g., increasing patients' infections due to incorrect surgical tools sterilization), costs unsustainability, introduction of new hospital strategies (e.g., investment on innovative technologies).

At the ASM, the CSSD has currently a mixed management. As already mentioned, the ASM comprises several hospitals, which became part of the ASM in different times and whose CSSDs were structured and managed differently (internal, mixed and outsourced services). The outsourced activities of the CSSDs are managed by a unique provider. The contract with this provider will expire soon, and this represents an opportunity to perform a reconfiguration of the whole CSSD.

For healthcare services, it is possible to identify alternative solutions (step 2) by taking into consideration the opportunities that are actually offered by the market, or by devising technically feasible but not ready-made solutions. This second avenue can be useful to detect the expected features and performance of the service for the specific hospital, which could form the basis of a competitive tender when this is required. The outputs of the application of the whole method by choosing the latter approach may be also of use by the specific hospital in terms of explicating healthcare needs, and it may serve as an important driver for claiming specific requirements to outsourced companies or to stakeholders at a macro level.

The alternatives identified by the ASM are based on their previous experiences and the current offers made by external providers. All the alternatives comply with regulations and standard requirements (e.g. concerning safety). Particularly, the three alternatives are defined as follow:

A1. Internal service: all the reprocessing and sterilization phases are handled "in house", involving internal staff and using (already) proprietary systems, technologies and surgical tools;

A2. External service: all the reprocessing and sterilization phases are handled through external resources. Staff, systems, technologies and surgical tools are outsourced to external companies;

A3. Mixed service: staff involved in the reprocessing and sterilization phases, including logistic, are outsourced to external companies. Systems, technologies and surgical tools are (already) proprietary.

Step 3 regards the identification of the dimensions of interest. As already mentioned in the Introduction section, the properties to be assessed may differ according to different kinds of technologies and contexts of application. Among all the dimensions currently in use for assessing health technologies, we propose the following: effectiveness/technical properties (T), organizational properties (O), safety (S), and economic (E) dimensions.

Technical properties, including "performance characteristics and conformity with specifications for design, composition, manufacturing, tolerances, reliability, ease of use, maintenance, etc." [191], may be better defined as "operational effectiveness" in the specific context of hospital services, thus including effectiveness, as another property frequently used in HTA. Specifically, operational effectiveness aims at better utilizing the organization's available resources, better implementing its processes and better accomplishing its goals. Nevertheless, in this specific context we refer it only to devices and structures within the service.

Organizational properties embrace both management issues, related to the planning and organization of the healthcare service, and the personnel's soft skills. Typically, the aspects most frequently used within this dimension are education, skills and centralization/decentralization [204].

Widely used within HTA, safety can be defined as "judgment of the acceptability of risk associated with using a technology".

The abovementioned four dimensions are general and comprehensive, and they can be, anyhow, shaped on the specific context, including different kinds of properties according to the characteristics of the service.

Step 4 concerns the definition of criteria of interest for each dimension. The aim of this step is to identify a comprehensive list of criteria related to the healthcare service to be assessed, at international level.

In our case study, a brainstorming between professionals working at the ASM was performed. Specifically, the professionals involved were: 1 clinical engineer specialized in health technologies, 1 clinical engineer specialized in provisioning, 1 engineer specialized in management, and 2 healthcare professionals working at the CSSD. Each participant performed a brief state-of-the-art review concerning indicators to be considered for guaranteeing a good quality of CSSD (e.g., [200], [205], [206]). During the brainstorming, the professionals debated together on both the literature and their perspective. This activity resulted in a first list of criteria. Then, criteria definitions were refined, in order to let them unambiguous,

comprehensive, direct, operational, understandable, as defined by [207] as the main properties for a good attribute.

At the end of step 4, the following criteria were identified:

- For the effectiveness/technical dimension: structure management; operational and technological level; characteristics of structures and installed equipment; surgical tools updating; process productivity; lead time of surgical tools; other.
- For the organizational dimension: possibility to recruit other staff; supervision and management competences; operational competence; organization flexibility; management of unplanned situations; coordination and organization synergy; other.
- For the safety dimension: responsibility of Quality Controls; service provider lock-in; clinical risk management; technological adjustment; other.

As for the economic dimension, only the total costs of each alternative was taken into consideration, as these data were readily available for all solutions.

The most important criteria were selected by an international panel (step 5). This step was divided into 4 tasks:

a. Design of the survey. The survey questionnaire was divided into the dimensions previously determined. For each dimension, all the identified criteria were listed, together with the editable field "other". The questionnaire was designed and administered through SurveyMonkey, a free web-based tool that allows developing customizable surveys. Respondents were asked to rank the criteria according to their importance (from the most to the less important). A short description of each criterion was provided in order to ensure that respondents understood their meaning. Moreover, to verify that panel members were representative of the target population, some preliminary questions, related to their professional background, were inserted.
b. Identification of channels for involving experts in the field. In addition to dedicated associations and societies devoted to the field of interest, one of the easiest ways for reaching international experts may be through LinkedIn. Moreover, LinkedIn Groups often gather professionals who enjoy being part of the online community and they may be interested in providing their support as "helpers", as defined by [208]. Furthermore, web-based surveys have been proven to be more reliable compared to telephone ones [209]. In our case study, the web link to SurveyMonkey was posted on the following LinkedIn groups: "Decontamination Sciences & Sterile Services Personnel", "Sterilization of Pharmaceuticals, Medical Devices & Biological Materials", "SVN-Sterilisatie Vereniging Nederland", "Sterile Processing Department Professionals". No individual invitations

were made, but a single call accompanied the public post. No rewards were foreseen for completing the questionnaire.

c. Collection of data. After a preliminary test, the survey questionnaire was posted on the abovementioned LinkedIn Groups. Data collection lasted 1 month.
d. Analysis of results and selection of criteria to be included in the MCDA model. In order to aggregate the respondents' judgments and obtain the overall level of importance of every criterion, it was necessary to convert the rankings into cardinal values. To this end, the rank ordered centroid (ROC) was employed, as it provides a reliable transformation when compared to other methods and it has been demonstrated to weight more accurately than the other rank-based formulae [210]. In summary, the application of ROC produced the ranking of all the criteria of a dimension, taking into account the respondents' judgments. Eventually, in order to ensure a balanced contribution of all the dimensions of interest to the assessment, it was decided to select the first two criteria in each ranking for the final steps of the methodology.

Step 6 concerns the set-up of the MCDA tool to be used. A key advantage of MCDA in HTA is its "ease of use", one of the most important characteristics for a tool to be actually used in practice. In this respect, among the available MCDA methods (e.g., AHP [211], ELECTRE [212]), PAPRIKA [168] is very intuitive and easy-to-use, even by decision-makers or assessors with limited knowledge of MCDA, and therefore could be the right choice in the case study. The set-up was made directly through "1000minds", an on-line tool made available by the authors of the method. The criteria selected in the previous step were validated by a clinical engineer, who also defined the possible levels of preference. Particularly, for each of the six selected criteria (two for each dimension) and the criterion representing the economic perspective, three different qualitative or quantitative levels of preferences were defined (Table 22). The levels vary from L1 (worst option) to L3 (best option).

A clinical engineer of the ASM, who possesses transversal skills, was required to assess the alternatives against each criterion using the proposed levels of preference.

In the last step 7, decision makers of the local health authority were required to perform pairwise comparisons through the PAPRIKA tool. In the case study, the local panel was composed by 6 decision makers, working at the ASM, with the following positions: director of clinical engineering service, chief medical officer, hospital risk manager, procurement officer, operating theater director, chief business officer. A precise explanation of qualitative values meaning was written in participants' mother tongue and provided to respondents. The weights (levels of importance) of the criteria, as well as the final ranking of the alternatives, were produced by *1000 minds* as a result of the answers provided during the pairwise comparisons.

ID	Dimension	Criterion	Level	Value
C1	Organizational	Supervision and management competences	L1 L2 L3	Poor Medium High
C2	Organizational	Operational competence	L1 L2 L3	Poor Medium High
C3	Effectiveness / Technical	Structure management	L1 L2 L3	Mean Time To Repair ≤ 1working hour Mean Time To Repair between 1 and 8 working hour(s) Mean Time To Repair > 8 working hours
C4	Effectiveness / Technical	Operational and technological level	L1 L2 L3	Up-Time < 95% Up-Time between 95% and 99% Up-Time ≥ 99%
C5	Safety	Responsibility of Quality Controls	L1 L2 L3	Poor Medium High
C6	Safety	Clinical Risk Management	L1 L2 L3	Poor Medium High
C7	Economic	Total cost	L1 L2 L3	More than 2,200,000 € Between 1,800,000 € and 2,200,000 € Less than 1,800,000 €

Table 22 – Criteria selected for the study with corresponding preference levels. Before starting the assessment, the meaning of values was carefully explained to the respondents

3.3.3 Results

From April 2016 to May 2016, 53 filled questionnaires were collected: 27 respondents (50.9%) fully or partially completed the questionnaire. Only 19 fully completed questionnaires (35.8%) were selected within the international panel as the respondents met the following pre-requisite: the international panel is a multidisciplinary and internationally group of professionals working in the field of sterilization process with at least 3 years of experience + certification in the field (e.g., Certified Sterile Processing and Distribution Technician - CSPDT, Certified Registered Central Service Technician - CRCST, Certified Instrument Specialist - CIS) or, since certification system is not offered in all the Countries, professionals with at least 10 years of experience in the field. The years of respondents' experience (average 16.68 years) and the number of certified professionals are reported in Table 23.

Of the 19 professionals within the international panel, 1 is from Indonesia, 1 from Canada, 4 from the USA, 2 from Australia, 1 from New Zealand, 3 from the UK, 1 from France, 5 from Italy, and 1 from the Netherlands.

Moreover, of the 19 professionals working within sterilization services, 2 are engineers, 7 technicians/nurses, 1 biologist, 7 managers, 1 product specialist, and 1 pharmacist.

Working experience (years)	Number of professionals	N. of professionals holding certifications
more than 30	2	2
from 20 to 29	5	2
from 15 to 19	4	2
from 10 to 14	4	1
from 3 to 9	4	4
Total	**19**	**11**

Table 23 – Short description of professionals included in the international panel

The average time for completing the survey was 11'41'' (min 4'31'', max 26'50''). The results of the ROC analysis are reported in Table 24 for each dimension.

ID	New ID	Criteria	Sum	Mean
O.1		Other staff recruitment	2.37	0.12
O.2	**C1**	**Supervision and management competence**	**4.68**	**0.25**
O.3	**C2**	**Operational competence**	**3.93**	**0.21**
O.4		Organization flexibility	2.39	0.13
O.5		Management of unplanned situations	2.47	0.13
O.6		Coordination synergy	1.79	0.09
O.7		Other	0.27	0.01
T.1	**C3**	**Structures management**	**4.23**	**0.22**
T.2	**C4**	**Operational and technological level**	**4.00**	**0.21**
T.3		Characteristics structure/installed equipment	2.87	0.15
T.4		Surgical tools updating	2.20	0.12
T.5		Process productivity	2.47	0.13
T.6		Lead time of surgical kit	2.63	0.14
T.7		Other	0.45	0.02
S.1	**C5**	**Responsibility of quality controls**	**5.71**	**0.30**
S.2		Service provider lock-in	2.61	0.14
S.3	**C6**	**Clinical risk management**	**5.78**	**0.30**
S.4		Technological adjustment	4.14	0.22
S.5		Other	0.48	0.03

Table 24 – Weighted sum and mean of cardinal values obtained through the application of the Rank Order Centroid (ROC) method, within dimensions. The highest values of importance in each dimension are displayed in bold and new IDs (C1-C6) were assigned to the corresponding criteria

As described in the previous section, the first two criteria of each dimension (highlighted in bold in Table 24) and the criterion representing the economic perspective, were used for setting-up PAPRIKA involving the local panel of professionals.

The MCDA assessment model is made up of seven criteria (C1-C7) with three preference levels each (L1-L3). It is worth mentioning that the PAPRIKA method, combining the levels of all criteria, builds a set of "potential" alternatives, which are then pairwise compared by the decision-makers in order to obtain the overall priorities that will be assigned to the actual investigated alternatives [168]. In the specific case 3^7=2,187 combinations of the levels and an equal number of potential alternatives are possible. However, 1000minds software is able to reduce this number by eliminating the potential alternatives that are dominated by others during the interactive assessment process. In the case study, the average number of pairwise comparisons that were made by the six respondents of the local panel was 29.5 (min 23, max 40) and the average time needed for completing the assessment process was 7' (min 6', max 9').

The median, mean and Standard Deviation of the obtained priorities, representing the relative importance (weights) of the criteria to the participants, are reported in Table 25 and radar chart of Figure 18.

Criterion	Median	Mean	Standard Deviation
C1	18.0 %	18.2 %	3.1 %
C2	18.4 %	17.9 %	2.5 %
C3	12.2 %	11.3 %	4.5 %
C4	11.0 %	9.8 %	4.5 %
C5	17.9 %	16.1 %	6.8 %
C6	15.9 %	16.6 %	6.3 %
C7	10.6 %	10.1 %	6.2 %

Table 25 – Median, mean and Standard Deviation of priorities

Particularly, the weight of a criterion corresponds to the average priority obtained by the highest level of preference of that criterion. For example (see Figure 18), since the average priority (mean) of the highest levels C4 and C1 are 9.8% and 18.2% respectively, C1 is almost twice as important as criterion C4.

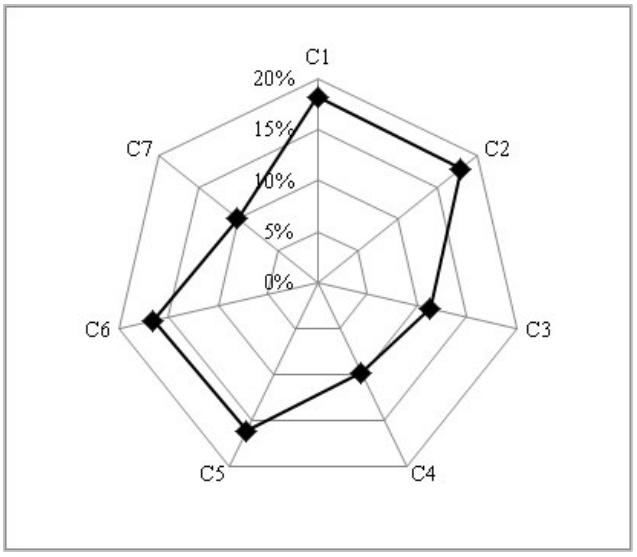

Figure 18 – Radar chart of weights. "C1": Supervision and management competence; "C2": Operational competence; "C3": Structures management; "C4": Operational and technological level; "C5": Responsibility of quality controls; "C6": Clinical risk management; "C7": Overall cost

Moreover, the "Marginal Rate of Substitution" (i.e., the rate at which the decision makers are ready to exchange an alternative for another one while maintaining the same level of utility) of the column criteria for the row criteria, is shown in Table 26.

Marginal Rate of Substitution		**C1**	**C2**	**C6**	**C5**	**C3**	**C7**	**C4**
Supervision and management competence	**C1**		1	1.1	1.1	1.6	1.8	1.9
Operational competence	**C2**	1		1,1	1.1	1.6	1.8	1.8
Clinical risk management	**C6**	0.9	0.9		1	1.5	1.6	1.7
Responsibility of quality controls	**C5**	0.9	0.9	1		1.4	1.6	1.7
Structures management	**C3**	0.6	0.6	0.7	0.7		1.1	1.2
Overall cost	**C7**	0.6	0.6	0.6	0.6	0.9		1
Operational and technological level	**C4**	0.5	0.5	0.6	0.6	0.9	1	

Table 26 –Relative importance of criteria (ratio between the weights of the row criteria to the column criteria)

Table 27 shows in the last column the normalized attribute weights (W_i) and, in the fourth, the single attribute scores (S_i), which correspond to the percentage of the contribution of a level in a criterion to the overall priority. In other words, the overall priority of an alternative (P) is calculated as:

$P = \sum_i \frac{W_i S_i}{100}$, *where i = 1, …, n (n, number of criteria)*

ID	Attribute	Level	Single attribute score (0-100)	Attribute weight (sum to 1)
C1	Supervision and management competence	Poor	0	0.182
		Medium	70.4	
		High	100	
C2	Operational competence	Poor	0	0.179
		Medium	83.5	
		High	100	
C3	Structure management	Mean Time To Repair ≤ 1working hour	0	0.113
		Mean Time To Repair 1-8 working hour(s)	55.9	
		Mean Time To Repair > 8 working hours	100	
C4	Operational and technological level	Up-Time < 95%	0	0.098
		Up-Time between 95% and 99%	67.9	
		Up-Time ≥ 99%	100	
C5	Responsibility of Quality Controls	Poor	0	0.161
		Medium	69.9	
		High	100	
C6	Clinical Risk Management	Poor	0	0.166
		Medium	68.2	
		High	100	
C7	Total cost	More than 2,200,000 €	0	0.101
		Between 1,800,000 € and 2,200,000 €	69	
		Less than 1,800,000 €	100	

Table 27 – Normalized criterion weights and single criterion scores (means)

All the six stakeholders of the local panel resulted to prefer CSSD internal service, followed by mixed service. The outsourced service was at the third and last position for all of the 6 stakeholders.

3.3.4 Discussion and conclusions

The results of the preliminary stage of the study, focused on the scouting and identification of an international panel of experts, allowed to identify the main aspects to be considered for assessing a CSSD. Even though 19 professionals involved is a considerable number for the scope of the work, the low percentage of respondents who completed the survey, compared to the total amount of collected questionnaires (35.8%), may suggest that the definition of the criteria has to be further simplified. On the other hand, LinkedIn showed to be a good channel for easily reaching experts in the field of interest at international level. Indeed, LinkedIn will be also used for sharing results of the work, in order to facilitate the dissemination process as it is one important moment of HTA.

At a local level, the application of the MCDA method using the previously selected attributes, allowed to identify the best solution among the stakeholders, through an easy-to-use and not time-consuming tool (7' per person on average). All the stakeholders resulted to prefer the internal service, followed by mixed service and out-sourced one. Their preference is in line with the characteristic of the area: the ASM comprises 5 hospitals, and it covers a wide area (3.479 km^2), with a population density of 58 persons/ km^2; the orographic distribution, together with road links, does not help a centralized management of patients and services. Moreover, an interesting result is related to the low weight given to the economic dimension. Indeed, since the current policy of different Italian Regions encourages hospitals to outsource non-core services, including CSSD, this might work as leverage for the hospital to claim an in-house CSSD.

Nevertheless, the results might change if the methodology were employed in a different context, an aspect that will be investigated in future research. Moreover, the proposed methodology is sufficiently versatile to be applied to any hospital services, maintaining consistency given by the international perspective but adaptable to local needs.

In conclusion, the proposed method aimed at assessing hospital service, integrating international experts' know-how and specific needs at a local level, and designed for combining practical needs of the healthcare institution with rigor of scientific approach, resulted to be successful. Decision makers of the local panel declared they were very satisfied by the usage of the method, stating it was easy-to-use, valid and helpful tool for taking decisions. However, some minor issues (i.e., better definition of criteria) have still to be solved, and the approach has to be extended and validated in different contexts.

3.4 Final remarks

This chapter analyzed hospital services, with the main purpose of finding an approach of assessment based on both scientific rigor and easiness-to-use from decision makers' perspective. A preliminary study aimed to assess a clinical engineering service through Multi-Criteria Decision Analysis; a second work aimed at studying a process considered crucial in the healthcare domain (i.e., process of surgical tools), through the application of lean management techniques, with the principle purpose to identify the main issues of the particular field of interest; the third study aimed at finding a useful tool for assessing the service previously studied in detail, following HTA approach and integrating Multi-Criteria Decision Analysis approach.

The final work allowed to identify a versatile approach that can be used also in different contexts, based on both international findings and decision makers' needs to have an easy-to-use tool. This method is based on the criteria considered as most important at international level, and it is shaped on particular needs of the hospital where the service has to be implemented.

Chapter 4
Medical equipment in Low Income Countries

The final part of this work concerns a preliminary study of medical equipment to be assessed in Developing Countries. Even though it is on its preliminary stage, a research on the principal needs of Developing Countries related to medical devices was performed, and a possible solution for improving management of medical devices is proposed. The research study was presented in 2016 at the XVI National Congress of Italian Association of Clinical Engineers (AIIC) [213].

4.1 Introduction

HTA is increasingly used in low- and high-resource nations and an aim among HTA agencies and scientists in developed countries is to assist low-income countries to "adopt" future local HTA activities [214].

One of the most challenging aspects to be considered for introducing a new technology in hospitals is the identification of the most suitable solution, shaped on the actual users' needs. Facing this issue is even more important and difficult in Developing Countries. Indeed, due to the lack of resources, avoiding waste of time and finding the most effective solution is crucial. Nevertheless, the literature states that medical technology-based projects are often implemented without sufficient assessment of local needs [215].

Even though nearly 80% of healthcare equipment available in some Developing Countries is donated or funded by international donors or foreign governments [216], only 10-30% of donated equipment becomes operational [217]. Reasons for unused equipment include mismanagement in the technology acquisition process, inefficient prioritization of available resources throughout the world, misalignment between the users' needs and the adopted technologies, low availability of service and costs related to the technologies maintenance, cultural barriers, lack of user education and training, lack of spare parts, and lack of effective technical support [218] [219]. Summarizing, medical equipment are often donated regardless to the environment where they will have to operate.

Moreover the persons' readiness to adopt a new technology is different from a place to another and it is deeply linked to cultural behaviors and personal predisposition. Another important and paradoxical aspect is related to the unsustainable costs of medical technology. Indeed, although more and more medical equipment manufacturers have moved towards Developing Countries (because of their cheaper labors), most of their productions still cost much higher than local productions and they cannot be directly sold in those countries' markets: customers need to import those products after adding high tariff [220].

On the other hand, donors should be more aware of the challenges and needs of end-uses, and communication between donors and recipients about these challenges should be improved. As stated by WHO [218], the main aspects to be considered to prevent inadequate medical equipment donations are:

- Donors lack awareness of the local realities of the intended recipients;
- Donors and recipients often do not communicate as equal partners in the pursuit of a common goal;
- Recipients have difficulty articulating to the donor how best they can be helped;

- The recipient's circumstances may lead them to believe that anything is better than nothing.

The donation process is summarized in Figure 19, provided by WHO [218].

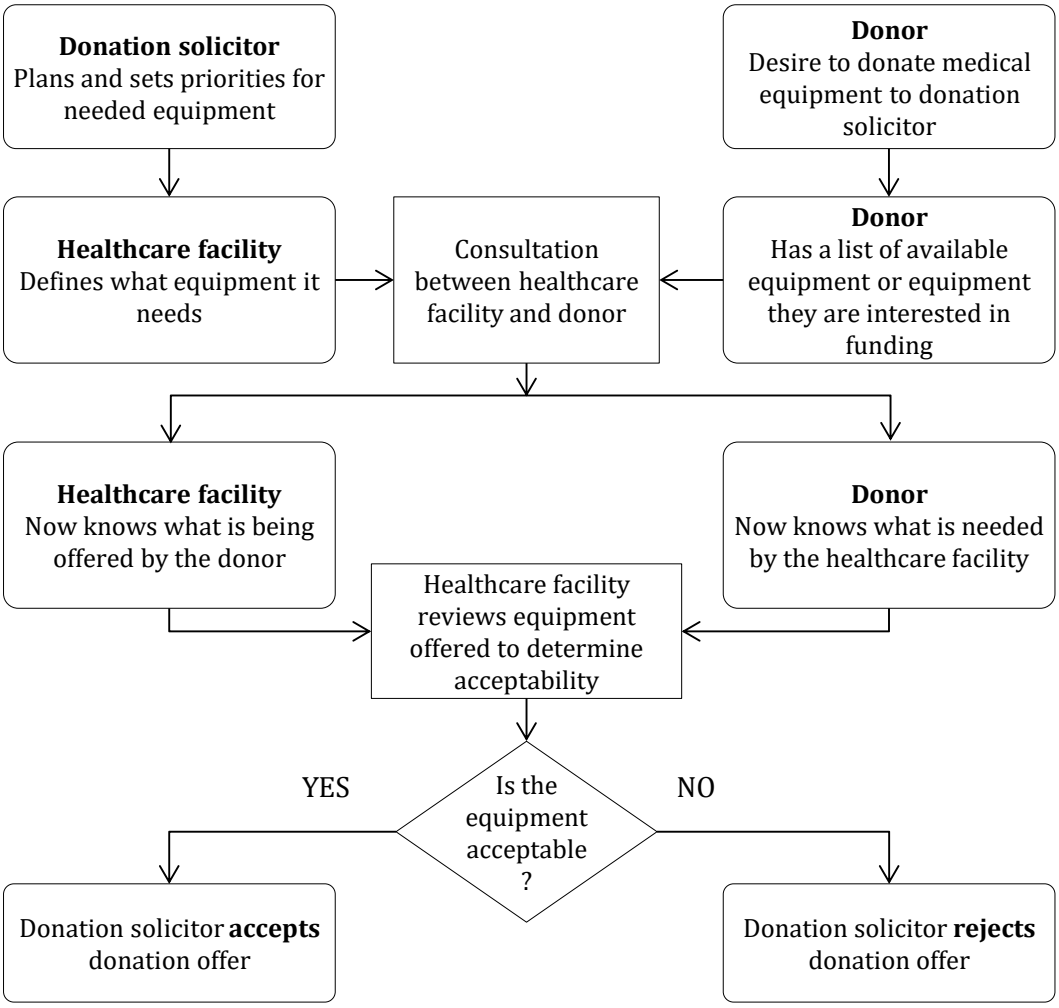

Figure 19 – Process for soliciting and offering donations of medical equipment (from [218])

The introduction of HTA in Developing Countries and the assessment of medical equipment before donation can be considered as a key point. At the same time, the importance of adapting global knowledge to local context of the specific Low-Income Country within the assessment is recognized as crucial [214].

4.2 The proposed solution

The proposed approach [213] aims to serve as a support for managing donations in Developing Countries, addressing the main challenges at the state-of-the-art and following the process recommended by WHO presented in the previous paragraph.

The proposed approach, briefly introduced in this paragraph, but not yet developed, is a web-based platform that serves as a meeting point between donors and solicitors, aimed at improving appropriateness in medical equipment donation. It can be divided into three main pars: Donors, Network and Donation Solicitors (Figure 20).

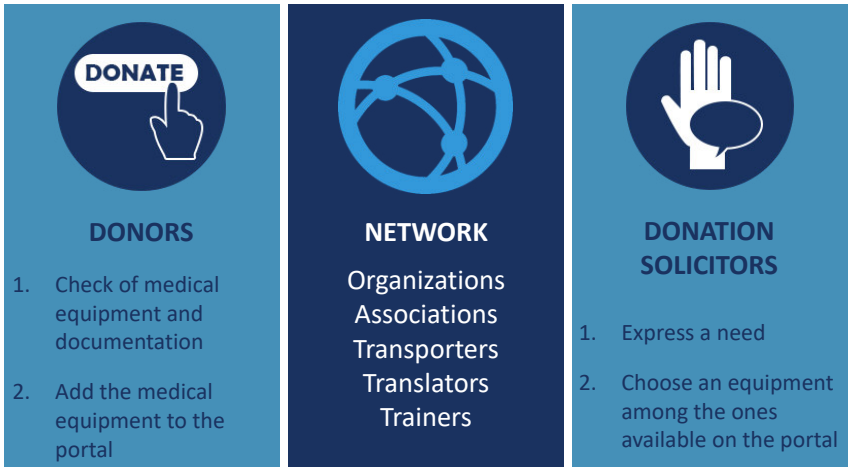

Figure 20 – Main pars (Donors, Network and Donation Solicitors) of the web-based platform that serves as a meeting point between donors and solicitors, aimed at improving appropriateness in medical equipment donation

First of all, a Network has to be created. The purpose of this approach, indeed, is to facilitate the interaction among actors already existing and interested in either medical equipment and supporting developing countries. This network can include, among others, corporations acting directly or through other organizations, individuals, non-governmental organizations (NGOs), associations devoted to developing countries' needs, and companies or private professionals capable of providing useful services or products (e.g., trainers, translators, transporters). These actors join into a dedicated web portal, after a structured preliminary assessment aimed at identifying how the company/professional can be of support in the specific context of medical equipment provision in developing countries, with particular attention to the main gaps identified by WHO and previously described. The same portal allows the interaction and

consultation between health care facility and donor, in order to evaluate the actual possibility of a donation.

The second part is dedicated to donors. A preliminary assessment of medical equipment to be donated is made through a checklist with a double purpose:

- To identify medical equipment technical performance;
- To verify the availability of guidance and documents related to medical equipment (e.g., user manual).

After assessment completion, the medical equipment is tagged and labeled through keywords (e.g., related to diseases, intended use, departments) in order to help solicitors in identifying their needs. Categorization of keywords represents a complex and important issue, since they have to be extremely easy to be understood by solicitors and grouped under "familiar" names, better if accompanied by pictures designed to simplify understanding. At the end of this phase, the medical equipment is published online on the web portal.

The third part is represented by donation solicitor. Solicitors express a need by choosing among the available keywords and groups aimed at facilitating the process of articulating how they can be helped. Otherwise, if solicitors already know which kind of medical equipment they need, they can directly search it through a dedicated search button. If the solicitor finds medical equipment of interest, they send a request to donor, and they directly interact each other.

During this consultation, solicitor can share with donor the particular needs related to the specific local constraints and resources with donor, verifying whether the medical equipment addresses all their needs. Particularly, during the consultation between donor and solicitor they verify:

- If the medical equipment addresses solicitors' needs;
- If medical staff capable of using the medical equipment is available;
- If technical staff capable of maintaining and checking the medical equipment is available;
- If user manual is written in a language they can understand.

Hence, solicitor and donor manage together the assessment on both sides, following a comprehensive checklist that takes into consideration all the related aspects and needs for a proper donation, and underlying what is lacking.

After their consultation, the lacking needs for a proper usage of the medical equipment are shared through the network and a call is launched through the web-platform. If someone among the actors involved in the network is able to be of support, they answer the call and become part of the medical equipment donation with their service/products, providing for example user manual translation, spare parts, transporting medical equipment, training medical or technical

staff (example in Figure 21). The process continues until the medical equipment completely addresses solicitor's needs and it is ready for a proper use.

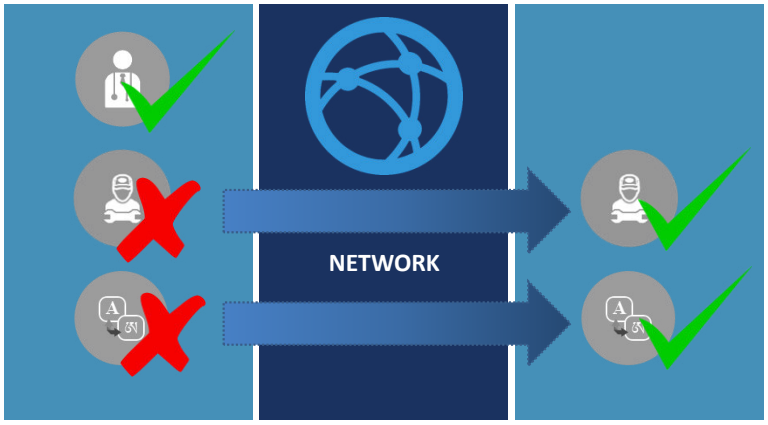

Figure 21 – Example of checks performed before donating medical equipment

4.3 Discussion

Even though it is on its preliminary stage, the proposed approach and the medical equipment assessment would help the donation process, reducing wastes and providing support for proper donation. It aims to focus on essential features, similarly to frugal innovation purposes, with particular interest to the actual local needs.

Moreover, it would serve as hub and help collaboration and cooperation among associations and organizations already devoted to supporting developing countries, as well as all the stakeholders involved into the process.

Lastly, it would allow individuals to be and feel of help, through the leverage of their own competences and skills.

Even though the proposed solution is not strictly based on HTA, it provides a structured approach for assessing medical equipment to be donated in Developing Countries, considering the most important aspects to be addressed for a proper donation, as highlighted by the World Health Organization.

Chapter 5
Conclusions

In this thesis, methodologies generally used for Health Technology Assessment and for reducing wastes, improving processes and services, were firstly investigated. Then, these methodologies were applied to both "classical" and innovative technologies, and they were modified according to specific needs, in order to combine scientific rigor with practical needs of decision makers.

The investigated technologies are medical devices, divided into technologies already in the market and technologies not yet available, and hospital services.

The investigated methodologies are Health Technology Assessment, divided into "traditional" HTA and horizon scanning; Multi-Criteria Decision Analysis, with a particular focus on PAPRIKA; and Lean Management, integrated with two other tools (i.e., Goal Question Metrics, and IDEF0) generally used in different sectors.

The main challenges in using traditional HTA approach have been identified (Chapter 1), and the main issue in healthcare practice of its application concerns the time offset between the request of assessing technologies and the availability of final reports. This issue causes as important consequence the HTA misuse from decision makers. Another identified challenge concerns the lack of data in certain technologies not often studied in the literature, conversely to technologies most frequently assessed through HTA (e.g., drugs). From this perspective, HTA can be considered a useful methodology for assessing technologies only if reports are provided in a short time and if data for comparing different technologies are available in the literature.

If data are lacking in the literature, Multi-Criteria Decision Analysis can be considered as a useful support for assessing technologies, since it provides a prompt and valuable support for decision makers, for both qualitative and quantitative data. Within the present study, PAPRIKA was successfully used for assessing hospital services (Clinical Engineering Department in Paragraph 3.1, and CSSD in Paragraph 3.3), and it was considered a valuable tool from decision makers perspective.

HTA approach strongly differs in relation to the particular kind of technologies, as presented in Chapters 2 and 3, where different technologies have been assessed. This result suits with the definition of HTA at the state-of-the-art, as presented in chapter 1, that emphasizes the heterogeneity of the methodology depending on the peculiarities of environment, settings and technologies to be assessed. Indeed, a standardized method for applying HTA is not available in the literature. In this thesis, a standardized approach was proposed for assessing health technologies whereas not sufficient data are available in the literature, exploiting Multi-Criteria Decision Analysis, and it was tested on a CSSD.

Furthermore, regarding process improvement, IDEF0 was used for mapping the entire process of surgical tools, and lean management techniques, together with Goal Question Metric (GQM) for identifying the specific question to be addressed for improving the process, allowed to reduce wastes and to simulate a newest process with considerable cost saving (Paragraph 3.2). The integration of Lean techniques, IDEF0 and GMQ represents an innovative, versatile, reproducible, and successful approach.

Even if the literature doesn't define "hospital service" as "health technology", some authors consider it as "technology asset", hence to be included in the more traditional assessment, even though not much works in the field are still available in the literature. Indeed, investigation on CSSD put the basis for continuing the study and identifying an overall and comprehensive methodology combining HTA with MCDA approaches, and integrating international experts' know-how with needs and peculiarities of the specific hospital at a local level. The swim-lane activity diagram of the proposed methodology, discussed in Paragraph 3.3, is presented in Figure 22.

The methodology was tested in an Italian healthcare authority and decision makers of the local panel declared they were very satisfied by the usage of the methodology that resulted to be easy-to-use and provided a rapid feedback.

Moreover, an approach similar to Horizon Scanning, a branch of HTA dedicated to innovative technologies, was used in the present work for assessing and designing an innovative technology for patients with chronic conditions (Paragraph 2.2). The application of the

methodology allowed to identify opportunities in the market and to foresee requirements aimed to address specific needs of patients.

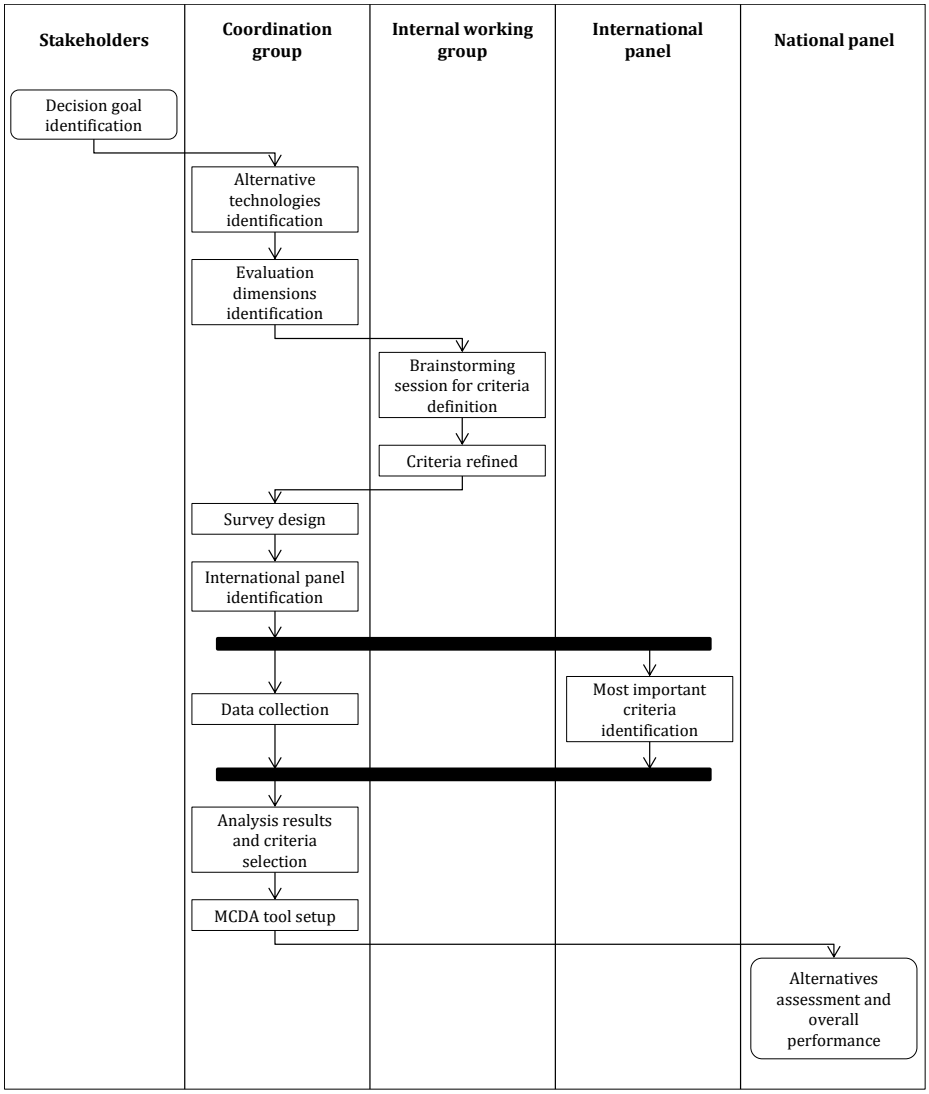

Figure 22 – Swim-lane activity diagram of the proposed methodology for assessing hospital services

Concluding, a simplified workflow of a path useful to Clinical Engineers from a practical perspective for selecting tools to be used for evaluating/assessing technologies within the healthcare domain can be briefly summarized as in Figure 23.

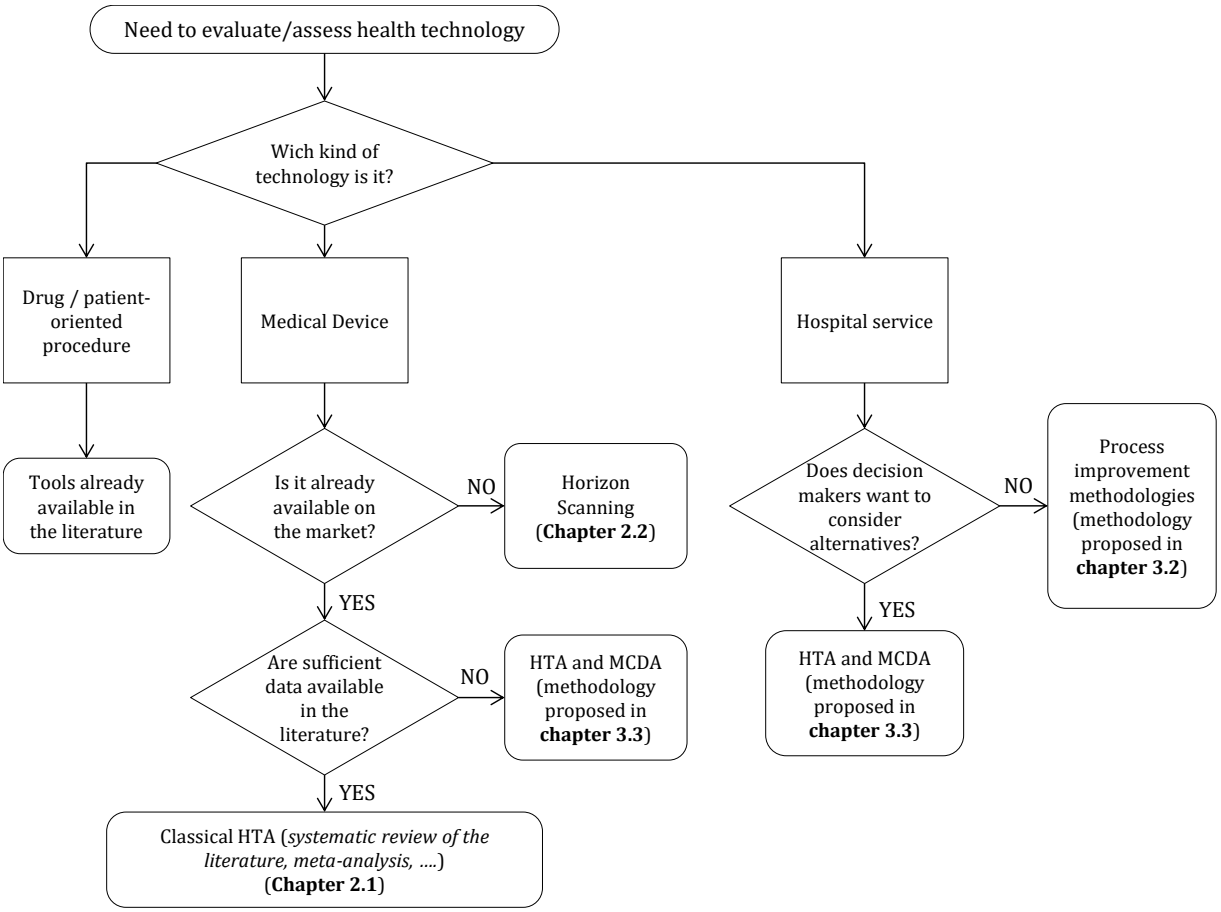

Figure 23 – Workflow of the proposed path for selecting tools to be used for evaluating/assessing technologies within the healthcare domain

Starting from the need to evaluate or assess a technology within the healthcare domain, the first question suggests to identify the typology of technology. In case it is a drug or a clinical trial or a procedure that directly involves patients, many tools to be adopted are already available in the literature.

If it is a medical device not yet in the market, horizon scanning approach can be adopted. This methodology can be exploited even for designed an innovative medical device, since it provides suggestions for identifying the most important features for letting the technology competitive in the market. An example is provided in Chapter 2.2.

If medical device is already on the market, it has to be considered whether sufficient data for performing a robust review are available in the literature. If not, MCDA approach can be exploited and the method presented in chapter 3.3 can be as well applied in this specific case. If

sufficient data are available in the literature, classical HTA based, for example, on systematic review of the literature or meta-analysis can be performed.

If technology is a hospital service (or procedures within hospital service), the first matter to be addressed is to understand whether decision makers want to compare the technology with other alternatives. If not, the attention has to be focused on process improvement techniques (e.g., lean management or Six Sigma), as presented in chapter 3.2. If decision makers want to consider other alternatives, the methodology presented in chapter 3.3 can be applied.

In order to let the overall proposed methodology currently used, it should be tested in a larger context, involving diverse environments and professionals, acquiring their feedbacks on its usefulness and ease-of-use in healthcare practice. This is the goal of future work.

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