TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE

MEASURING THE MATURITY OF BUSINESS INTELLIGENCE IN HEALTHCARE: SUPPORTING THE DEVELOPMENT OF A ROADMAP TOWARD PRECISION MEDICINE WITHIN ISMETT HOSPITAL

Luca Gastaldi

Politecnico di Milano — Department of Management, Economics and Industrial Engineering

Via Lambruschini, 4/B, 20156 Milano, Italy
E-mail: luca.gastaldi@polimi.it

Astrid Pietrosi

Mediterranean Institute for Transplantation and Advanced Specialized Therapies (IRCCS-ISMETT)
Discesa dei Giudici, 4, 90133, Palermo, Italy
E-mail: apietrosi@ismett.edu

Sina Lessanibahri*

Politecnico di Milano(Polimi) — Department of Management, Economics and Industrial Engineering
Via Lambruschini, 4/B, 20156 Milano, Italy

Universidad Politécnica de Madrid (UPM) —Department of Industrial Engineering, Business Administration and Statistics
Calle de José Gutiérrez Abascal, 2, 28006 Madrid

E-mail: sina.lessanibahri@polimi.it

Marco Paparella

Politecnico di Milano — Department of Management, Economics and Industrial Engineering
Via Lambruschini, 4/B, 20156 Milano, Italy
E-mail: marco.paparella@polimi.it

Antonio Scaccianoce

Mediterranean Institute for Transplantation and Advanced Specialized Therapies (IRCCS-ISMETT)
Discesa dei Giudici, 4, 90133, Palermo, Italy
E-mail: ascaccianoce@ismett.edu

Giuseppe Provenzale

Mediterranean Institute for Transplantation and Advanced Specialized Therapies (IRCCS-ISMETT)
Discesa dei Giudici, 4, 90133, Palermo, Italy
E-mail: gprovenzale@ismett.edu

Mariano Corso

Politecnico di Milano — Department of Management, Economics and Industrial Engineering
Via Lambruschini, 4/B, 20156, Milano, Italy
E-mail: mariano.corso@polimi.it

Bruno Gridelli

Mediterranean Institute for Transplantation and Advanced Specialized Therapies (IRCCS-ISMETT)
Discesa dei Giudici, 4, 90133, Palermo, Italy
E-mail: bgridelli@ismett.edu

** Corresponding author*

Keywords: healthcare, business intelligence, maturity model, maturity level

Acknowledgments

This study was mainly funded by Mediterranean Institute for Transplantation and Advanced Specialized Therapies (IRCCS-ISMETT). Sina Lessanibahri has received research grants from EMJD Programme European Doctorate in Industrial Management (EDIM), which is funded by the European Commission, Erasmus Mundus Action 1.

Abstract

Business Intelligence (BI) has the potential to disrupt the processes through which agents offer healthcare services. Despite this key role, most healthcare organizations fail in implementing or extending BI suites from the pilot niches, in which these digital solutions are usually developed and tested, to larger domains. In fact, healthcare practitioners lack comprehensive models that suggest the priorities to follow for progressive development of a BI solution. We suggest that the unsuccessful adoption of business intelligence is due to lack of maturity and readiness of information areas within the healthcare organizations. Given the complexities embedded in healthcare sector, the readiness assessment should be tailored for these complexities. This paper aims to start filling these gaps by developing a model through which: (i) to measure and increase the maturity of BI solutions within healthcare organizations and (ii) enable extensive processes of benchmarking and continual improvement.

Keywords: healthcare, business intelligence, maturity model, maturity level

1 INTRODUCTION

The introduction of new and sophisticated medical technologies, the global trend of increased longevity, and the increase in non-transmittable chronic diseases have the potential to drive the cost of healthcare to unsustainable levels [1]. Public and private healthcare organizations are focusing their efforts on finding new, more affordable levels of care, and increasing efficiency [2, 3] . In order to do this, information technologies have a fundamental role in transforming data into intelligence to improve patient care, healthcare facilities, and process management [4].

The appropriate management of healthcare facilities and processes, and the attendant enormous quantity of data managed with advanced BI programs, can similarly allow the more efficient use of financial, human, and material resources by directing better allocation, eliminating waste, and detecting corruption practices early on [5].

Given the crucial role of data in supporting the problem solving in organizations, BI has become an important area of study for both researchers and practitioners [6, 7]. Davenport and Harris [8] define BI as a set of technologies and processes that use data, statistical and quantitative analysis, explanatory and predictive models, and fact-based management, which drive decisions and actions, enabling an accurate understanding of business performance.

The field of BI has improved significantly [9], and has promising applications in the healthcare domain [5, 6, 10]. In fact, BI can drastically improve services' delivery processes in healthcare organizations and help them to progress along the continuum from intuitive to precision medicine [11].

Despite the disrupting potentials of BI in healthcare and studies reporting reduced costs (e.g., [3]) and improved outcome of care delivery [12] many healthcare organizations are not using BI [13]. This fact raises questions regarding the pervasiveness and adoption of BI systems, and the scale of their generalizability. Moreover, studies regarding the factors affecting the successful implementation of BI in healthcare domain are limited [14] and there is a lack of comprehensive models that help practitioners with the priorities that should be followed to develop a BI solution [6].

This paper aims to start filling these gaps by developing a model through which:

- to measure and increase the maturity of BI solutions within healthcare organizations;
- to enable extensive processes of benchmarking and continual improvement.

The overall goal is to provide healthcare practitioners with actionable knowledge and tools to support the development of their roadmaps toward exploiting the disrupting potential of BI.

The remainder of the paper is organized as follows. In Section 2, we discuss the theoretical background of the work. In Section 3, we show the research methodology and the data measures we used. In Section 4, we discuss the key findings of our analyses. Finally, in Section 5, we discuss the theoretical and empirical implications of our work, and fruitful directions for further research on the topic.

2 THEORETICAL BACKGROUND

We have organized the theoretical background of the paper into two sections. The first describes the latest developments in the field of healthcare BI, and reveals the lack of models and tools to support the development of these solutions. The second focuses on BI maturity models, and identifies the opportunity to improve the models in consonance with healthcare organization and management decisions.

2.1 BI in Healthcare

Healthcare organizations have been under constant pressure to not only achieve more outcomes with fewer resources [14], but also to progressively become information-driven systems [15]. Considering that the amount of data recorded by electronic health records and medical registries is growing rapidly [16, 17], healthcare organizations are trying to draw upon tools such as BI in order to improve their efficiency and effectiveness [18, 19].

If BI was initially perceived as merely a collection of tools for data analysis [20], over time this perception has changed, and BI is now considered an organizational capability with strategic impact on an organization's success [21]. Today, BI is usually referred to as a set of methods, theories, methods, processes, and techniques that converts data into useful and valuable information for business purposes [22]. BI solutions help decision-makers by providing practical information in the right form, at right time, and in right place [23]. Organizations can use BI to manage information effectively and efficiently, and reach higher business goals [19]. In general, BI is developed to provide decision-makers with actionable information—utilizing data integration and analytic techniques [24].

As recently highlighted in Gartner report [25], the market of BI and business analytics has grown significantly and has become the CIOs first technology investment priority. Also, the awareness of its potential benefits is increasing [26, 27]. However, the implementation of BI in healthcare proceeds relatively slowly and in an ad hoc way [14]. Generally, when it comes to Healthcare Information Systems (HISs) some studies have reported decreased costs (e.g., [28]), higher income (e.g., [29]), and improved productivity (e.g., [30]). Other studies have reported a negative or non-existent impact of BI on the performance of healthcare organizations [14, 31], with positive outcomes that become less significant

moving from institutional to larger scale studies [32]. Successful implementation of BI in healthcare relies on understanding and analyzing the peculiarities and complexities of the domain [33, 34], though the main focus of the literature on BI was traditionally on the industrial sector [33]. Moreover, our knowledge about interrelations between BI dimensions and how these interrelations affect BI success is limited [35]. Thus, this study will attempt to shed light on the effect of healthcare idiosyncrasies/complexities and the interdependencies between BI dimensions on the success factors of BI in healthcare.

2.2 BI Maturity Models

Maturity models were introduced for the first time in the 1970s [36] to guide users from an initial state to a desired or naturally existing end state by outlining an evolutionary path [37, 38]. The key objective of maturity models is to detect the gap between current and desired states, and to anticipate an evolutionary transformation in order to advance the maturity, and eventually achieve the desired state [39]. The evolutionary path implies that the progress toward higher maturity stages is incremental, and realized through a set of intermediate states [40].

Dimension, level, and assessment tools are the principal elements of maturity models [38]. Dimensions are mutually exclusive capability areas that construct the clusters of interrelated activities [41]. With each dimension come measures, which are used to assess the maturity of the dimension [42]. Levels are the maturity states that the dimensions assume. Each level has a distinct descriptor of the detailed corresponding state of the maturity of the dimensions [43]. Assessment instruments are either qualitative or quantitative, and questionnaires and scoring models are among the most common [37]. The research methods that are most commonly used for maturity model construction are focus groups, Delphi, review of the literature, or case studies [38].

While there are several BI maturity models in the literature, they focus mainly on data and information, without considering the domain's specific complexities [44] and few studies focus specifically on corporate healthcare idiosyncrasies in model development (e.g., [39, 44]). These studies do not consider the interdependencies and the relations between different components and dimensions. Generally, most of the maturity models introduced in the literature are fixed-level models, i.e., models in which a fixed number (typically five) of maturity levels are assumed [41]. The main drawback of the fixed-level models is that they are not developed with the interdependencies between the dimensions in mind [45, 46], hence these models cannot provide comprehensive guidelines for prioritizing the dimensions that should achieve further improved maturity levels. In fact, the importance of the interdependencies grows with the complexity of the domain of interest. Thus, for complex systems, such as healthcare, it is crucial to

explicitly measure and incorporate the correlations between different domains, and identify the possible interdependencies among them. Only in this case it is possible to provide organizations with not only adequate readiness assessment, but also with actionable frameworks that can be used to develop roadmaps toward the desired maturity levels. Thus, the objective of this research was to develop a maturity model tailored for healthcare idiosyncrasies. Moreover, we developed artifacts to measure the synergies and the interdependencies between the dimensions. By analyzing the maturity and the interrelations among dimensions, we define the shortest and most prominent evolutionary path toward achieving the desired maturity levels.

3 RESEARCH METHODOLOGY

In order to accomplish the study's goals, we built upon a Clinical Inquiry Research (CIR) project we did from October, 2012 to May, 2013 with:

- The Mediterranean Institute for Transplantation and Advanced Specialized Therapies (ISMETT), a 656-employees (86-beds) private hospital in Italy with a recognized experience in using digital technologies (and especially BI) for improving healthcare treatment[1];
- Five hospitals representative of the variety of the Italian healthcare industry and with experience in the development of BI solutions.

All six hospitals were selected because of their experience in BI—measured in terms of the percentage of budget delivered to BI from 2008 to 2013.

CIR, developed by Schein [47], is a well-known and comprehensive collaborative form of research. CIR has a distinguishing difference in is in the setting of the activity [48]; in CIR the practitioners who need help, will have the directing role and, because of this, learning opportunities will emerge [47] and data will be revealed. In this setting researcher have a process facilitator role and helps practitioners to discover insights through self-diagnosis/self-intervention [49].

The request for joint collaborative research came directly from the leadership of ISMETT, interested in developing a model to assess the maturity of the BI system in the healthcare domain with application to

[1] *ISMETT is public-private partnership between the Region of Sicily (through the Civico Hospital in Palermo) and UPMC, an integrated global health enterprise headquartered in Pittsburgh, and one of the leading not-for-profit health systems in the United States. ISMETT is the first hospital in Southern Italy to receive Joint Commission International (JCI) accreditation, and has been recently authorized by the Italian Ministry of Health as an IRCCS. IRCCSs are research-oriented hospitals operating in Italy with competences in research and treatment of important diseases, which represent a national network where basic and translational biomedical research is undertaken in synergy with the delivery of high qualitative healthcare. For more information, see* [58].

its BI system. A Research Task Force (RTF)[2] was formed in November 2012. Modeled on the leading literature on collaborative research [50], the RTF included both researchers and practitioners, and subdivided its work into four main phases: knowledge acquisition, diagnosis, criteria setting, and implementation design.

Business process analysis and mapping [51], face-to-face interviews, and multi-participant interactive dialogues [52] were the principal collaborative mechanisms utilized. Periodic meetings were organized in order to progressively share the achieved knowledge, slightly re-orient the research process, and discuss the empirical as well as theoretical implications of the findings.

In the next two sections, we will describe how we developed the BI maturity model, and how we applied it to ISMETT with the goal of understanding the adequacy level of BI implementation with respect to organizational and managerial needs, and of defining a roadmap for eventual improvement in exploiting the tool.

3.1 BI Maturity Model Development

Given the complexity of creating the model, its development required the design of intermediate constructs [40]. First, we analyzed the literature extensively, also taking into account all the sectors in which BI maturity is evaluated (not only healthcare) with the aim of understanding the criteria used to define and select the metrics by which to assess the maturity of the BI solution, and to identify the potential logic of grouping these metrics. This exercise allowed for the production of a preliminary version of the BI maturity model, which the RTF progressively discussed and refined.

Information acquisition and knowledge systematization were accomplished in multiple modes depending on the specific intent, on the specific stage of model elaboration and on the experience developed. Initially, brainstorming sessions [53] were used within the RTF to elicit ideas for model conceptualization. The objectives of this phase were to assess the potential value of the maturity model, and to identify the different areas and components characterizing a BI solution in healthcare.

Next, we used the consensus decision-making mode to evaluate the evolving model. Such types of techniques are very useful after brainstorming [40], and aim to find the best solution to a problem by letting the group weigh in on the advantages and disadvantages of each alternative solution. We accomplished this by collecting the judgments and votes of each member of the RTF on different

[2] T*he RTF leveraged both the qualified professional expertise on BI of ISMETT researchers and the in-depth knowledge of the creation of systems of the researchers of Politecnico di Milano.*

classifications for the areas, as well as on the components and metrics characterizing the maturity model. We also sent e-mails to a panel of power-users of the BI solution developed at ISMETT to solicit their detailed opinions on various topics, and solve the most critical issues.

Last, we used the concept-sorting mode [53] to flesh out the components in which the various metrics could be grouped. This mode of knowledge acquisition is useful once the maturity model is outlined, and the key areas of the BI models have been identified [40].

Acting as a process facilitator, the external researchers supported ISMETT practitioners in the definition of 119 metrics to assess the maturity of BI solutions in healthcare settings. These metrics have been subdivided into 23 components grouped into four different areas:

- *Functional area (6 components, 47 metrics)*: the set of components that represent the different functionalities of the BI solution (e.g., the possibility of actively supporting decision-making in the clinical, quality, production, or economic domain);
- *Technological area (7 components, 20 metrics)*: the set of components that represent the technological features of the BI solution (e.g., the number of interoperability standards supported by the solution);
- *Diffusional area (3 components, 27 metrics;)*: the set of components that measure the pervasiveness of the BI solution (e.g., its use by clinicians and nurses);
- *Organizational area (7 components, 25 metrics)*: the set of components that describe how the organization manages the BI solution (e.g., strategic coherence between BI development and company needs);

For each metric, the RTF identified a question with four answering options that reflect the increasing maturity of the BI solution according to the specific metric considered. See Tables A.1, A.2, A.3 and A.4 in the Appendix for an overview of the different areas, components, metrics, and maturity levels.

The RTF produced a questionnaire to assess the specific maturity levels for each metric. All questions were tested and refined with a set of BI managers and experts from the five Italian healthcare organizations involved with the CIR project. Specifically, we conducted multiple interviews to analyze and understand whether the model and the questionnaire were comprehensive, understandable, usable, and accurate. We revised the metrics and the maturity levels in order to make them mutually exclusive and collectively exhaustive. Moreover, we slightly changed the wording of the questions used to assess the maturity levels.

3.2 BI Maturity Model Application

After validation of the model, the RTF presented it to ISMETT's leadership, which asked the researchers to assess the maturity of its BI solution, and, based on the assessment, to co-define a roadmap for fully exploiting BI when necessary.

Through a snowball technique [54], the RTF involved in this phase of the CIR project were not only ISMETT experts in BI areas, but also the managers coordinating the development of BI solutions, and the power users handling day-to-day operative issues. Five informants were involved in the assessment of the maturity of the BI solution at ISMETT.

The questionnaire was sent to these informants via e-mail, and contained an endorsement by the strategic board (together with its request of a full commitment to the tasks to be accomplished). We gave each informant the time to scan and preliminarily fill out the questionnaire. Next, we organized face-to-face meetings in which we clarified any anomalies or inconsistencies in the answering of the questionnaire, and led a discussion of informants' perspectives to find a shared synthesis. Consensus decision-making was the principal technique used to come to a comprehensive positioning on the maturity model.

It is important to note that for each metric we asked the informants not only to evaluate the current (April 2013) maturity levels achieved at the hospital, but also the levels that were expected to be achieved in the next three years—according to the strategic plans already programmed and/or what seemed feasible targets in the considered timeframe. This choice further increased the level of actionability of the knowledge generated through the model, which was able not only to easily spot inharmonious developments related to the BI solution, but also to consider the gaps that were reasonable to fill in the near future.

After completing the questionnaire, ISMETT initiated collective thinking on how to achieve—starting from its current position in the maturity model—the different maturity levels expected for the various metrics in the next three years. Researchers supported this reflection by systematizing in a unique and coherent framework:

- the different interventions planned by the hospital for each area of the model (derived from a joint reflection on ISMETT's position in the BI maturity model);

- some critical issues that were central for achieving the expected levels of maturity (derived partially from analysis of the literature and partially from an analysis of other healthcare organizations that were developing a BI solution[3]);
- further evolutions that could be interesting to accomplish for making the BI solution as synergic as possible with other state-of-the-art digital solutions in the healthcare domain (these evolutions are the results of three face-to-face interviews with the ISMETT CEO).

The RTF considered all the stimuli that emerged in this phase, recognizing that these stimuli were not sufficient to develop a roadmap that would allow a real prioritization of the different interventions and investments. As a result, the RTF organized specific meetings to reflect on the different relationships among the components (and, thus, metrics) characterizing the model. To ensure reliability [55] all meetings were facilitated by two researchers, recorded, transcribed, and coded.

A cross-analysis of all the meetings allowed the researchers to propose a preliminary version of a framework of interdependencies (need for a prioritization in the development) and synergies (need for a concurrent development) among the different components of the BI maturity model. Exploiting the knowledge of ISMETT experts, the RTF reviewed the framework through a multi-participant interactive dialogue [52], and worked together on a final version that was reviewed and then validated by the BI experts, managers, and users in the other five hospitals involved in the CIR project.

Finally, we linked the framework with the maturity levels of the various components of the BI model in order to determine different clusters of components to be prioritized. To accomplish this task, we: (i) averaged the maturity levels of the different metrics characterizing each component; (ii) translated the various prerequisites and synergies of each component into a comprehensive value, calculated according to a predefined set of scores[4]; (iii) checked the consistency of the results in the RTF; (iv) presented them to the BI experts at ISMETT to collect their feedback; and (v) validated the different clusters of component prioritization.

4 FINDINGS

We have organized this section according to the different outputs achieved during the CIR project. First, we present the BI maturity model and the questionnaire through which it was possible to assess a generic

---

[3] From this viewpoint, the RTF leveraged both the assets of an Observatory see [59] *for a description of the Observatory), and the managerial knowledge and expertise of UPMC International.*

[4] Four points for each strong prerequisite of the component; 3 points for each prerequisite of the component; 2 points for each strong interdependence of the component; 1 point for each interdependence of the component.

healthcare organization with that model (see Section 4.1). Next, the application of the model to ISMETT allowed us to: (i) assess the maturity of its BI solution, as well as its developments in the near future (see Section 4.2); (ii) provide useful elements for developing an action plan in order to increase the maturity according to managerial strategic goals, and, thus, the effectiveness of its BI solution (see Section 4.3).

4.1 Maturity Model and Questionnaire

Tables A.1 to A.4 provide an overview of the BI maturity model. The tables are organized in developmental areas, components, and metrics. For each metric, the tables report the different maturity levels defined through the continual interaction between the researchers and practitioners. Some metrics (e.g., the frequency of goal definition in Table A.1) have sub-metrics that reflect the different domains in which the metric can be measured (e.g., definition of the goal in the economic domain, in the production domain, and in the qualitative domain). In these cases, the maturity levels reported in the table are valid for each sub-metric[5].

The questionnaire is organized into five sections. The first section asks for general information (e.g., number of departments, beds, employees) related to the healthcare organization answering the questionnaire, and its information system (e.g., number of workstations, partners/suppliers of digital technologies, reports produced through the BI system). The idea was to:

- obtain descriptive variables that would allow a characterization of the context in which the company is inserted in order to cluster the healthcare organizations answering the questionnaire;
- collect useful quantitative data to better understand and interpret the answers given by each healthcare organization answering the questionnaire.

The remaining four sections focus on the developmental area identified in Section 3.1. For each metric and/or sub-metric, the RTF produced a question with four possible answers that reflect the increasing levels of maturity of the BI solution. As an example, consider the following question relating to the granularity of the economic data usable by the BI solution in supporting the function of "goal definition":

---

[5] *The economic, production, and qualitative domains are used in several components of the BI maturity model. Economic domain refers to costs and revenues of the healthcare organization, e.g., the cost of a hospitalisation. Production domain refers to volumes and hospital length of stay in the health care organization, e.g., the number of admissions per department. Qualitative domain refers to the quality of the output of the health care organization, e.g., the number of admissions related to a Major Diagnostic Category (MDC).*

What is the level of granularity of the data on which the BI solutions can work in order to support the definition of a goal in the economic domain (cost and revenues)?

1. *In more than 50% of cases the BI solution does not support the definition of a goal in the economic domain; when the BI solution supports this functionality, the relative data can be considered only at a corporate level (e.g., when it is necessary to define the goals to be achieved, the BI solution presents and allows working on drug costs for the entire healthcare organization);*
2. *In more than 50% of cases the BI solution supports the definition of a goal in the economic domain with data at the level of unit and/or ward (e.g., when it is necessary to define the goals to be achieved, the BI solution presents and allows working on the costs of diagnostic procedures of each department constituting the healthcare organization);*
3. *In more than 50% of cases the BI solution supports the definition of a goal in the economic domain with data at the level of the single event or cure episode (e.g., when it is necessary to define the goals to be achieved, the BI solution presents and allows working on the cost of a DRG);*
4. *In more than 50% of cases the BI solution supports the definition of a goal in the economic domain with atomic data at the level of the single treatment procedure (e.g., when it is necessary to define the goals to be achieved, the BI solution presents and allows working on the costs of the HRs for each treatment);*

4.2 Assessment of Actual and Expected BI Maturity

In healthcare, BI is often partial or absent compared to other industries [56]. In most cases, BI is considered an accounting tool. Rare are the cases in which BI is used as a tool to manage economic, production, quality, and clinical areas simultaneously [56]. Beginning in 2011, ISMETT expanded use of BI in all the areas in order to increase monitoring of utilization of resources, with high levels of correlation among allocation of resources, utilization, and outcome. In view of a prospective growth of offered services, in 2012, ISMETT wanted to identify the level of BI maturity acquired, and the level that the organization would have to reach considering the prospect of growth over the next three years

ISMETT's assessment of the BI maturity model allowed it to support, with sound evidence, management's impression that most of the efforts made by ISMETT regarding its BI solutions had been in the technological area, in which the hospital had achieved an extremely high overall level of maturity. The other development areas were expected to be improved over the three years following the assessment precisely to fill the gaps with technological maturity. This is consonant with what is suggested by both the literature (e.g., [40]) and the practitioners involved in the research project: inhomogeneous developments

tend to be resource-consuming, risky, and ineffective in exploiting the disrupting potential of BI to develop effective roadmaps towards precision medicine.

As an example of the considerations that the assessment enabled, consider the components in the functional area (Table A.1). Figure 1 highlights high maturity levels for the components, which were expected to grow in the three years after the assessment. Among the four canonical phases characterizing a management control system (F_1, F_2, F_3 and F_4), the one relative to "measurement" was the most supported by the BI solutions. Looking at the expected maturities, respondents envisioned a development profile once again driven by "measurement," but in which the other phases surpassed or approached level 3 of maturity.

In order to accomplish these goals, ISMETT put a focus on improving the maturity of both data quality—a substantial prerequisite for any further development in the BI solution—and functional integration, to synergistically exploit the results achieved in the different phases, and progressively integrate the various data sources.

In the final report produced for ISMETT, the researchers of Politecnico di Milano explained and detailed the position of all the components characterizing the BI maturity model. When present, they carried out specific analyses for sub-metrics. For example, at the moment of evaluation, the ISMETT BI solution was extremely mature in managing data in the production and economic domains (volumes and times), while it looked to improve its support in the qualitative domains.

——— INSERT FIGURE 1 AROUND HERE ———

4.3 Supporting the Development of a Roadmap toward Precision Medicine

One of the main limitations of the maturity models in the literature is that the relationships among the different metrics and components are often tacit [38]. In the spirit of tackling this issue, the RTF produced Figure 2, which, considering two components of the model (X and Y), allowed to identify four different relationships between them:

- *Strong prerequisite* (►): this relationship indicates that in order to increase the maturity of X, it is necessary to have previously reached mid-high (3 or 4) levels of maturity in Y[6];
- *Prerequisite* (→): this relationship indicates that in order to increase the maturity of X, it is suggested to have previously reached mid-high (3 or 4) levels of maturity in Y;
- *Strong interdependence* (••): this relationship indicates that it is necessary to simultaneously evolve the maturity of X and Y;
- *Interdependence* (•): this relationship indicates that it is suggested to simultaneously evolve the maturity of X and Y.

The figure provides a healthcare organization aiming to increase the maturity of its BI solution with important information to lead each intervention/investment. A vertical analysis of the table emphasizes the prerequisites and the interdependencies necessary and/or suggested to increase the maturity of a component. For example, consider the component "active support to decision-making" (the fourth column in the functional area). As indicated in Figure 1, ISMETT had a maturity level of 2.22, consonant with current needs, but expected to achieve a level of 3.11 over the next three years. To realize this maturity growth, it is not sufficient to improve the level of data granularity, the functional support, and the frequency through which the BI solution supports this function in economic, production, and qualitative domains. Figure 2 suggests that many other components, both within the same development area as well as outside it, are critical in achieving this improvement.

In the final report delivered to ISMETT, the researchers of Politecnico di Milano detailed why a component was a prerequisite or interdependent with another component, and what ISMETT could do in order to leverage these relationships and accelerate the development process of its BI solution.

Figure 2 is extremely useful, even if read horizontally. In this case it is possible to verify the impacts produced by a component on the others, emphasizing the components that have the highest priority due to the fact that they are a strong prerequisite of many other components. Starting with the table, the RTF translated the various prerequisites and synergies of each component into a comprehensive value, calculated as indicated in Section 3.2. Crossing the resulting values with the maturity levels assessed through the questionnaire (e.g., the values in Figure 1 for the functional area), it has been possible to

---

[6] For example, it is necessary to reach at least level 3 of maturity for the metric relative to BI strategy (presence of a corporate strategy at a corporate level, see O_1 in Table A.4) in order to increase the maturity of the percentage of users who can access the system (D_1 in Table A.3).

determine the four clusters depicted in Figure 3[7], the consistency of which was validated through an interaction with ISMETT experts in BI.

The four clusters are the following:

- *Strategic components*: components in which ISMETT should consolidate its investments because they are already mature, but are also highly relevant (and often strong prerequisites) for the evolution of other components;
- *Critical components*: components on which ISMETT has to focus as soon as possible because they are not mature, and are highly relevant (and often strong prerequisites) for the evolution of other components;
- *Consolidated components*: components in which ISMETT should invest marginal resources because they have received a number of investments in the past (reflected in high levels of maturity), and their development has less influence on the development of other components;
- *Postponable components:* components that should be considered after having tackled the critical components, since their development has less influence on the development of other components, even if, in a logic of homogeneous development of the BI solution, their maturity levels have to be aligned with others eventually.

The four clusters of components have to be approached with different modalities, resources, and timings. In the final report delivered to ISMETT the researchers of Politecnico di Milano detailed these aspects, providing further elements for the hospital's roadmap towards precision medicine.

——— INSERT FIGURE 2 AROUND HERE ———

——— INSERT FIGURE 3 AROUND HERE ———

In order to develop a specific and effective action plan, and to homogenize the maturity levels of the various components, the RTF prioritized further improvement of the components. Starting with Figure 2, it translated the various prerequisites and synergies of each component into a comprehensive value (see Figure 4). Consider two components Y_j and X_j, where Y_j a prerequisite of is (or has synergy with) X_j. To

[7] *We removed two components from the figure—BI strategy and BI budget—since they are outliers. According to practitioners these components are so relevant that they represent two pre-requisites of any BI solution aiming to be effective within a health care organization.*

prioritize the development of components, a score is assigned to each component Y_j based on Eq.1; the higher values of the assigned score indicate immediate investment or focus on the component.

$$\text{Score } Y_j = \sum_{i=1}^{n}\left[\left(EM_{X_i}\text{-}AM_{X_i}\right)\frac{1}{AM_{X_i}}\frac{\left(PS_{Y_jX_i}\text{-}AM_{Y_j}\right)+\left|PS_{Y_jX_i}\text{-}AM_{Y_j}\right|}{2}\right] \quad \forall j = 1 \dots n \quad \textbf{Eq. 1}$$

Where:

- $\boldsymbol{n}$: *number of components*
- $\boldsymbol{Score\ Y_j}$: *overall score given to component* Y_j,
- $\boldsymbol{EM_{X_i}}$: *expected maturity of component* X_i *infuture*
- $\boldsymbol{AM_{X_i}}$: *current maturity of component* X_i
- $\boldsymbol{PS_{Y_jX_i}}$: *number of points given besed on the relationship (prequisite or interdependency) between* Y_j *and* X_i

The first part of Eq.1 takes into account the difference between the expected and current maturity of the dependent component X_i, and the second coefficient ($\frac{1}{AM_{X_i}}$) considers the inverse of the current maturity level of X_i, thus, the higher the difference between expected and actual maturity and the lower the current maturity of the dependent component X_i; the higher the score given to Y_j. Finally, the third coefficient calculates the positive part of the difference of the relation score and the current maturity of Y_j**.** If the current maturity of Y_j is less than the maturity needed to develop X_i, this coefficient is positive; otherwise, it is zero. For example, if the component Y_j is a prerequisite of X_i, but the current maturity of Y_j is high enough (3 or 4), the third coefficient is zero and eliminates the effect of the relation on the score of Y_j. Figure 4 depicts the calculated scores of ISMETT's BI components. As shown in the figure, BI budget, BI strategy, and process coverage are the first three areas that need more attention and/or investment.

——— INSERT FIGURE 4 AROUND HERE ———

5 CONCLUSIONS

The principal contribution of this study is the development of a BI maturity model and the relative assessment questionnaire, which are specific for the healthcare industry, and allow to effectively address

the pressing issues associated with BI solutions within it. In addition, the designed maturity model was applied to ISMETT BI to directly show the applicability of the research results.

The research showed that the development of a BI solution is essentially an evolutionary process, and that is possible to identify several discrete stages in the roadmap toward a full exploitation of BI in the realization of precision medicine. We proposed that an inadequate level of BI system maturity could be a major reason behind the failure of so many BI initiatives. We mapped the relationships among the components of the BI solution (especially those among different development areas), depicting the different interactions in terms of interdependencies and synergies to be leveraged to successfully extend BI solutions to larger domains.

We also showed how the level of maturity should always be consonant with organizational structure, management decisions, and strategic changes in terms of growth foreseen in the near future. Furthermore, the maturity should be periodically re-evaluated to adjust BI implementation and diffusion according to company and environmental changes.

Moreover, by activating organization-wide processes of involvement, the BI maturity evaluation model described in this paper allows healthcare practitioners to monitor and predict on an objective basis the quality of their BI solutions and the processes that produce them. The artifacts are based on several components and metrics, which not only enable any type of benchmarking regarding the strategies through which different healthcare organizations develop a BI solution, but are useful tools for understanding which components to focus on in a healthcare organization in order to progressively make its BI solutions more efficient and effective, providing scope for continual improvement.

We envision three streams of research emerging out of our work. Following the software process maturity paradigm [57], the first stream could focus on organizational attempts to characterize BI practices by empirically examining the consensual benefits attributed to a mature BI solution. For example, it is important to use the BI maturity model to systematically measure a hospital's ability, commitment, goals, and roadblocks in evaluating its performance on the different metrics, and to develop benchmarks to transition to higher levels of maturity. In this research stream, the basic premise is that consistent application of well-defined and measured BI processes, coupled with continual process improvement, will streamline BI project management, and substantially improve the productivity and data quality of BI solutions.

A second stream of research could focus on the metrics, the maturity levels, the prerequisites, and the synergies that have been developed. Based on their application at ISMETT, they appear to be

comprehensive. But it is unclear whether all metrics and maturity levels are of equal value with respect to BI maturity assessment. And it is unclear how to effectively weigh and precisely measure the strength of both the synergies and the interdependencies that have been considered. It would be interesting to conduct field studies (in the form of surveys) that include a number of organizational (e.g., size, system architecture, structural attributes, resources, management attitude, and culture) and environmental (e.g., institutional and competitive forces, technology support structures) determinants of efforts that companies exert in pursuing initiatives to upgrade their BI maturity levels.

Finally, an important future direction would be to employ our model/questionnaire to assess BI maturity in different healthcare organizational settings and, based on those assessments, test a set of hypotheses relating to the consequences of BI maturity on their performance. Moreover, if the maturity model were applied to all (or the majority of) healthcare organizations in a regional healthcare system, the model could provide the regional healthcare directorate with useful knowledge to address the design of homogenizing policies and continual improvement strategies at a regional level.

REFERENCES

1. Qaseem A, Alguire P, Dallas P, et al (2012) Appropriate use of screening and diagnostic tests to foster high-value, cost-conscious care. Annals of Internal Medicine 156:147–150.

2. Romanow D, Cho S, Straub D (2012) Riding the Wave: Past Trends and Future Directions for Health IT Research. MIS quarterly 36:3–10.

3. Pine M, Sonneborn M, Schindler J, et al (2012) Harnessing the power of enhanced data for healthcare quality improvement: lessons from a Minnesota Hospital Association Pilot Project. Journal of healthcare management 57:406–18.

4. Li M, Mao J (2015) Hedonic or utilitarian? Exploring the impact of communication style alignment on user's perception of virtual health advisory services. International Journal of Information Management 35:229–243. doi: 10.1016/j.ijinfomgt.2014.12.004

5. Fichman RG, Kohli R, Krishnan R (2011) The role of information systems in healthcare: Current research and future trends. Information Systems Research 22:419–428. doi: 10.1287/isre.1110.0382

6. Chen H, Chiang R, Storey V (2012) Business Intelligence and Analytics: From Big Data to Big Impact. MIS quarterly 36:1165–1188.

7. Zeng L, Li L, Duan L, et al (2012) Distributed data mining: A survey. Information Technology and Management 13:403–409. doi: 10.1007/s10799-012-0124-y

8. Davenport T, Harris J (2007) Competing on Analytics: The New Science of Winning. Boston (MA)

9. Gandomi A, Haider M (2015) Beyond the hype: Big data concepts, methods, and analytics. International Journal of Information Management 35:137–144. doi: 10.1016/j.ijinfomgt.2014.10.007

10. El-Gayar O, Timsina P (2014) Opportunities for Business Intelligence and Big Data Analytics in Evidence Based Medicine. In: 2014 47th Hawaii International Conference on System Sciences. IEEE, pp 749–757

11. Christensen CM, Grossman J., Hwang J (2009) The innovator's prescription. McGraw–Hill, New York (NY)

12. Tremblay MC, Hevner AR, Berndt DJ (2012) Design of an information volatility measure for health

care decision making. Decision Support Systems 52:331–341. doi: 10.1016/j.dss.2011.08.009

13. Hanson R (2011) Good health information–an asset not a burden! Australian Health Review 35:9–13.

14. Foshay N, Kuziemsky C (2014) Towards an implementation framework for business intelligence in healthcare. International Journal of Information Management 34:20–27. doi: 10.1016/j.ijinfomgt.2013.09.003

15. Gastaldi L, Lettieri E, Corso M, Masella C (2012) Performance improvement in hospitals: leveraging on knowledge asset dynamics through the introduction of an electronic medical record. Measuring Business Excellence 16:14–30.

16. Kuiler EW (2014) From big data to knowledge: An ontological approach to big data analytics. Review of Policy Research 31:311–318. doi: 10.1111/ropr.12077

17. Tremblay MC, Berndt DJ, Luther SL, et al (2009) Identifying fall-related injuries: Text mining the electronic medical record. Information Technology and Management 10:253–265. doi: 10.1007/s10799-009-0061-6

18. Gastaldi L, Corso M (2012) Smart healthcare digitalization: using ICT to effectively balance exploration and exploitation within hospitals. International Journal of Engineering Business Management 4:1–13.

19. Brooks P, El-Gayar O, Sarnikar S (2013) Towards a Business Intelligence Maturity Model for Healthcare. 46th Hawaii International Conference System Sciences (HICSS)

20. Anandarajan M, Anandarajan A, Srinivasan C (2012) Business intelligence techniques: a perspective from accounting and finance. Springer Science & Business Media, Berlin

21. Wixom B, Watson H (2012) The BI-based organization. In: Herschel R (ed) Organizational Applications of Business Intelligence Management: Emerging Trends. IGI Global, Hershey (PA), pp 193–208

22. Rud O (2009) Business intelligence success factors: tools for aligning your business in the global economy, 18th ed. John Wiley & Sons

23. Negash S (2004) Business intelligence. The communications of the Association for Information Systems 13:54.

24. Turban E, Sharda R, Delen D, Efraim T (2007) Decision support and business intelligence systems. Pearson Education India

25. Gartner (2015) Flipping to Digital Leadership: Insights from the 2015 Gartner CIO Agenda Report. Stamford

26. Lahrmann G, Marx F, Winter R, Wortmann F (2011) Business intelligence maturity: Development and evaluation of a theoretical model. In: Proceedings of the 44th Hawaii International Conference on System Sciences. pp 1–10

27. Chuah M, Wong K (2011) A review of business intelligence and its maturity models. African journal of business management 5:3424–2428.

28. Borzekowski R (2009) Measuring the cost impact of hospital information systems: 1987–1994. Journal of health economics 28:938–949.

29. Ayal M, Seidman A (2009) An empirical investigation of the value of integrating enterprise information systems: the case of medical imaging informatics. Journal of Management Information Systems 26:43–68.

30. Lucas FL, Sirovich BE, Gallagher PM, et al (2010) Variation in cardiologists' propensity to test and treat: is it associated with regional variation in utilization? Circulation Cardiovascular quality and outcomes 3:253–60. doi: 10.1161/CIRCOUTCOMES.108.840009

31. Agarwal R, Gao GG, DesRoches C, Jha AK (2010) The digital transformation of healthcare: Current status and the road ahead. Information Systems Research 21:796–809.

32. Chaudhry B, Wang J, Wu S (2006) Systematic review: impact of health information technology on quality, efficiency, and costs of medical care. Annals of internal medicine 144:742–752.

33. Mettler T, Vimarlund V (2009) Understanding business intelligence in the context of healthcare. Health informatics journal 15:254–264. doi: 10.1177/1460458209337446

34. Avison D, Young T (2007) Time to rethink health care and ICT? Communications of the ACM 50:69–74.

35. Popovič A, Hackney R, Coelho PS, Jaklič J (2012) Towards business intelligence systems success: Effects of maturity and culture on analytical decision making. Decision Support Systems 54:729–739.

36. Gibson C, Nolan R (1974) Managing the four stages of EDP growth. Harvard Business Review 52:76–88.

37. Fraser P, Moultrie J, Gregory M (2002) The use of maturity models/grids as a tool in assessing product development capability. In: International Engineering Management Conference (IEMC),. Cambridge, pp 244–249

38. Marx F, Wortmann F, Mayer J (2012) A maturity model for management control systems. Business and Information Systems Engineering 4:193–207.

39. Blondiau A, Mettler T, Winter R (2015) Designing and implementing maturity models in hospitals: An experience report from 5 years of research. Health informatics journal 1460458215590249

40. Sen A, Ramamurthy K, Sinha A (2012) A model of data warehousing process maturity. IEEE Transactions on Software Engineering 38:336–353.

41. Lahrmann G, Marx F (2010) Systematization of Maturity Model Extensions. In: Winter R, Zhao JL, Aier S (eds) Global Perspectives on Design Science Research. Springer, Berlin, pp 522–525

42. Mettler T, Rohner P (2009) Situational maturity models as instrumental artifacts for organizational design. Proceedings of DESRIST

43. Lahrmann G, Marx F (2010) Business intelligence maturity models: an overview. VII conference of the Italian chapter of AIS (itAIS)

44. Brooks P, El-Gayar O, Sarnikar S (2015) A framework for developing a domain specific business intelligence maturity model: Application to healthcare. International Journal of Information Management 35:337–345. doi: 10.1016/j.ijinfomgt.2015.01.011

45. de Bruin T, Freeze R, Kaulkarni U, Rosemann M (2005) Understanding the main phases of developing a maturity assessment model. In: 16th Australasian Conference on Information Systems,. Sydney, p paper 109

46. Maier A, Moultrie J, Clarkson P (2009) Developing maturity grids for assessing organisational capabilities: Practitioner guidance. 4th International Conference on Management Consulting, Academy of Management

47. Schein E. (2008) Clinical inquiry/research. In: Reason P, Bradbury H (eds) The SAGE Handbook of Action Research: Participative Inquiry and Practice. Sage, Thousand Oaks, pp 266–279

48. Coghlan D, Brannick T (2005) Doing action research in your own organization. SAGE Publications, London (UK)

49. Stebbins M, Shani A (2009) Clinical inquiry and reflective design in a secrecy-based organization. The Journal of Applied Behavioral Science 45:59–89.

50. Mohrman AMJ, Mohrman SA (2004) Self-designing a performance management system. Collaborative Research in Organizations: Foundations for Learning, Change, and Theoretical Development

51. Womack JP, Jones DT (2003) LEAN THINKING. Simon and Schuster, New York (NY)

52. Mikaelsson J, Shani A (2004) Rethinking and transforming product development. In: Adler N., Shani A.B. SA (ed) Collaborative research in organizations. Sage, Thousand Oaks, pp 181–196

53. McGraw K, Harbison-Briggs K (1989) Knowledge acquisition: Principles and guidelines. Prentice-Hall, New York (NY)

54. Patton M (2002) Qualitative evaluation and research methods ., 3rd ed. Sage, Thousand Oaks

55. Bourgeois LJ, Eisenhardt KM (1988) Strategic decision processes in high velocity environments: Four cases in the microcomputer industry. Management science 34:816–835.

56. Zheng G, Zhang C, Li L (2014) Bringing Business Intelligence to Health Information Technology Curriculum. Journal of Information Systems Education 25:317–326.

57. Krishnan M, Kellner M (1999) Measuring process consistency: Implications for reducing software defects. IEEE Transactions on Software Engineering 25:800–815.

58. Ferré F, Giulio A, Valerio L, et al (2014) Health System Review: Italy. Health Systems in Transition 16:1–168.

59. Gastaldi L, Corso M (2013) Academics as effective orchestrators of interorganizational change and development: the experience of Italian observatories. In: Pasmore W, Woodman R, Shani AB (Rami), Noumair DA (eds) Research in Organizational Change and Development (Vol. 21). Emerald, Bingley (United Kingdom), pp 59–119

Figure 1

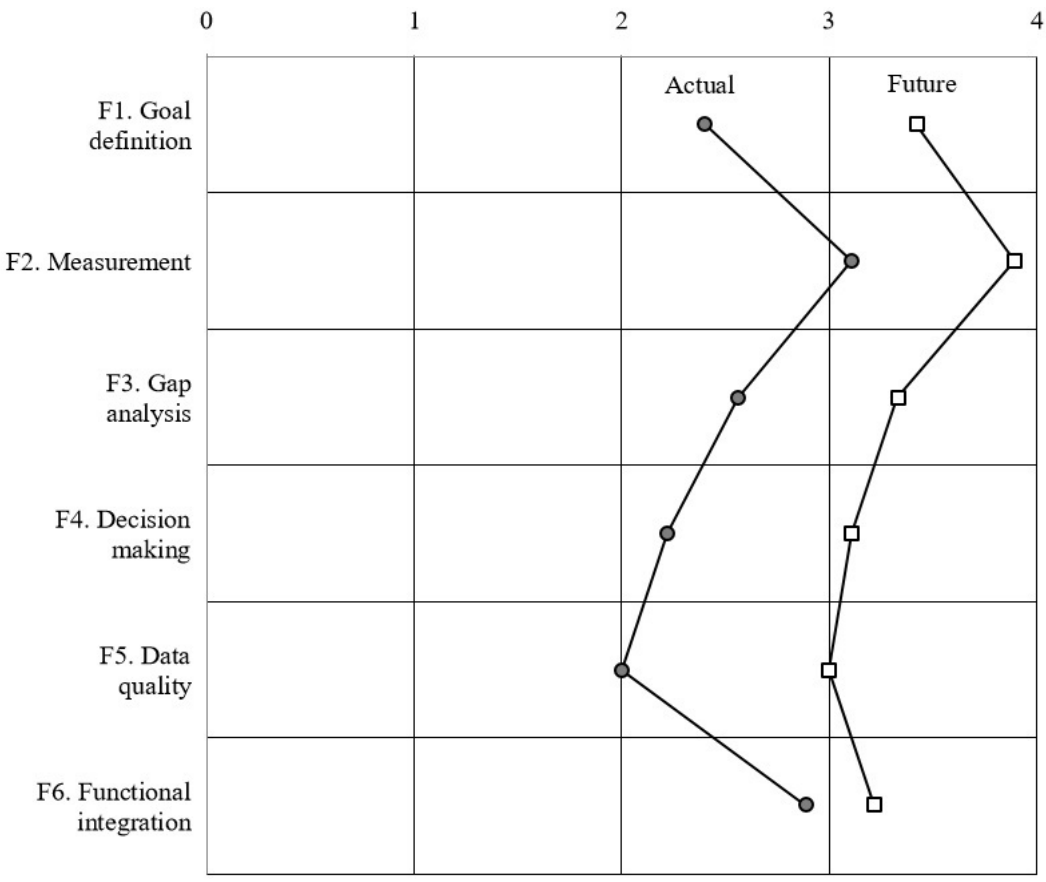

Figure 1. ISMETT position on the functional components of the BI maturity model

Figure 2

Y*		X: Functional						Technological							Diffusional			Organizational						
		F1. Goal definition	F2. Measurement	F3. Gap analysis	F4.Decisions making	F5. Data quality	F6. Functional integration	T1. BI architecture	T2. Reporting	T3. Interface	T4. User profiling	T5. Technological	T6 Standards	T7. Data provisioning	D1. Accessing users	D2. System users	D3. Process coverage	O1. BI strategy	O2. BI budget	O3. Organization	O4. Key-user	O5. User capabilities	O6. Competence	O7. Partner/supp
Functional	F1. Goal definition	–	→	▶	▶	••	••		→	•		•		•	•	•	••			→		•		
	F2. Measurement		–	→	▶	••	••		→	•		••		•	•	•	••			→		•		
	F3. Gap analysis			–	▶	••	••		••	•		•		•	•	•	••			→		••		
	F4.Decisions making				–	••	••			•		••			•	•	••			→		••		
	F5. Data quality	••	••	••	••	–	•	•	•			•	•	•										
	F6. Functional integration	••	••	••	••	•	–		•							→				•		→		
Technological	T1. BI architecture	→	→	→	→	••	▶	–				→	•							→	•			
	T2. Reporting			••		•	•		–	•					•	▶						•		
	T3. Interface	•	•	•	•				•	–					•	▶								
	T4. User profiling										–				→	→								
	T5. Technological integration	•	••	•	••	•	→					–	•	••			▶							•
	T6 Standards					•	→	•				•	–	•			→							→
	T7. Data provisioning	•	•	•	▶	•	▶					••	•	–						•				
Diffusional	D1. Accessing users	•	•	•	•				•	•					–	•				→		••	•	
	D2. System users	•	•	•	•										•	–	•			•		•	••	
	D3. Process coverage	••	••	••	••		▶		→						→	•	–							
Organizational	O1. BI strategy	▶	▶	▶	▶	▶	▶	→				→	→	▶	▶	▶	▶	–	••	•			→	→
	O2. BI budget	→	→	→	→	→	▶	▶	→	→	→			▶	→	▶	▶	••	–					
	O3. Organizational coverage						•			•				•		••		•		–	•	••	•	▶
	O4. Key-user capabilities	→	→	→	→			•							→	→				•	–	•		
	O5. User capabilities	•	•	•	•				•						••	•				•	•	–		
	O6. Competence improvement	•	•	•	•										•	••				•	→	▶	–	
	O7. Partner/supplier coordination											•												–

* → = Prerequisite to X component; ▶ =Strong prerequisite to X component; • = Interdependence; •• = Strong interdependence

Figure 2. Interdependencies and synergies among the components of the BI maturity model

Figure 3

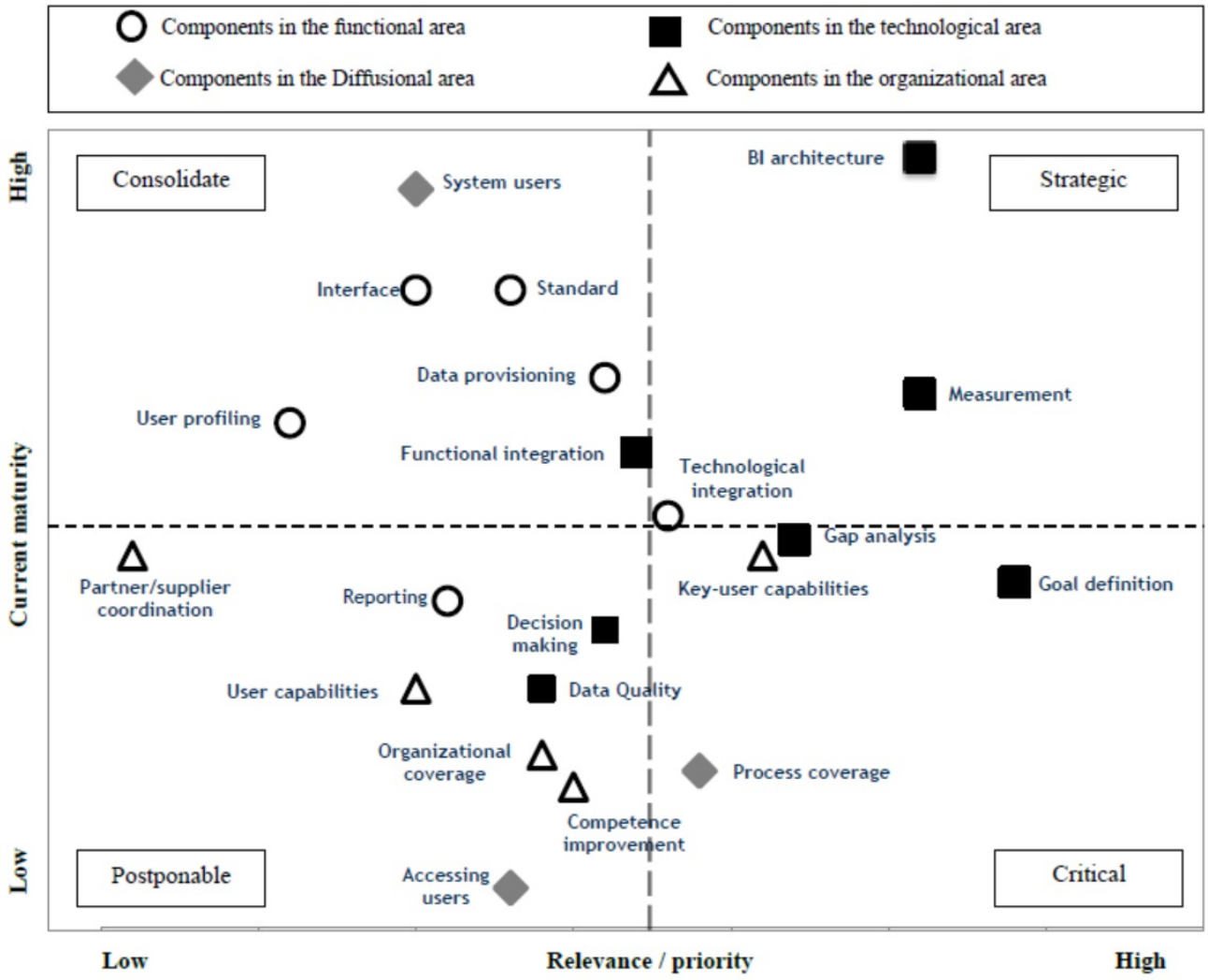

Figure 3. Relevance and maturity for healthcare business intelligence at ISMETT

Figure 4

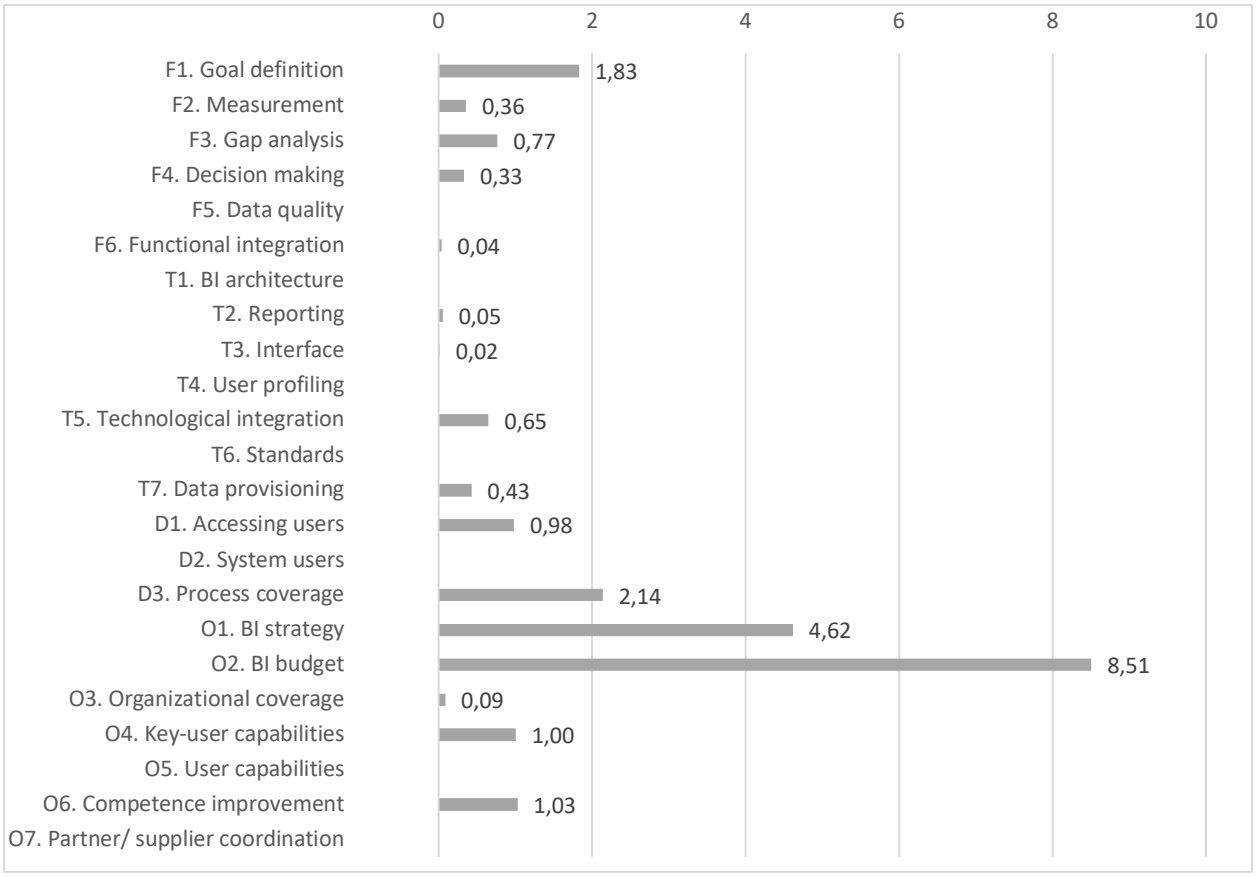

Figure 4. Priority scores of the components for healthcare BI at ISMETT

Annex A

TABLE A.1

Component	Metric	Sub-metric*	Maturity levels			
			Level 1	Level 2	Level 3	Level 4
F_1. Goal definition	Level of data granularity**	Economic Production Qualitative	None or organization	Unit or ward	Event or cure episode	Treatment procedure
	Functional support	Economic Production Qualitative	No support	Input of consolidated targets	Budget development	Budget dynamic management
	Frequency**	Economic Production Qualitative	Annually	Quarterly	Monthly	Weekly or daily
F_2. Measurement	Level of data granularity**	Economic Production Qualitative	None or organization	Unit or ward	Event or cure episode	Treatment procedure
	Functional support	Economic Production Qualitative	No support	Only some operative units, manually	All operating units, manually	All operating units and automatically**
	Frequency**	Economic Production Qualitative	Quarterly	Monthly	Weekly or daily	Real time
F_3. Gap analysis	Level of data granularity**	Economic Production Qualitative	None or organization	Unit or ward	Event or cure episode	Treatment procedure
	Functional support	Economic Production Qualitative	No support	Only data collection	Data collection and gap visualisation	Data collection and automatic gap analysis
	Frequency**	Economic Production Qualitative	Quarterly	Monthly	Weekly or daily	Real time
F_4. Decision making	Level of data granularity**	Economic Production Qualitative	None or organization	Unit or ward	Event or cure episode	Treatment procedure
	Functional support	Economic Production Qualitative	No support	Ex post analysis	OLAP	Active support to decision making
	Frequency**	Economic Production Qualitative	Quarterly	Monthly	Weekly or daily	Real time
F_5. Data quality	Controls on inbound data	Economic Production Qualitative	No automatic controls	Controls on less than 40% of data	Controls on less than 80% of data	Systematic controls on all managed data
	Controls on outbound data	Economic Production Qualitative	No automatic controls	Controls on less than 40% of data	Controls on less than 80% of data	Systematic controls on all managed data
F_6. Functional integration	Internal data integration***	Economic Production Qualitative	None	Integration of less than 30% of data	Integration of less than 70% of data	Integration of more than 70% of data
	External data integration****		None	Two	Three, on less than 50% of processes	Three, on more than 50% of processes
	Integration among functional areas*****		None	Two	Three	All

* *Some metrics (e.g. the frequency of goal definition) have sub-metrics reflecting the different domains in which the metric can be measured (e.g,. economic, production or qualitative data); in these cases, the maturity levels reported in the table are valid for each sub-metric*

** *The maturity levels for this metric/sub-metric are considered achieved by the healthcare organization only if it is valid in more than 50% of cases; for instance, a healthcare organization is at level 3 of maturity for the frequency of goal definition only if in more than 50% of cases its BI system allows it to define goals every month; for more information, see the "prevalence logics" in §4.1*

*** *Internal data integration refers to the extent to which the BI system allows to work in an integrated manner on the data in a specific domain (economic data, production data or qualitative data)*

**** *External data integration refers to the extent to which the BI system allows to work in an integrated manner on the data in different domains (e.g. economic and production data)*

***** *Integration among functional areas refers to the extent at which the BI system allows to work in an integrated manner on the four functional areas characterising the BI process (goal definition, measurement, gap analysis and decision making)*

Table A.1. Components, metrics, and maturity levels in the functional area

TABLE A.2

Component	Metric	Sub-metric*	Maturity levels			
			Level 1	**Level 2**	**Level 3**	**Level 4**
T_1. BI architecture	Structure of the architecture		No architecture	No decoupling	Transactional and analytics decoupling	Multi-level architecture for analytics
T_2. Reporting	Quality**	Economic Production Qualitative	Static	Static with graphic data visualisation	Dynamic data navigation	Dynamic statistical simulation
	Distribution**	Economic Production Qualitative	Paper-based	Digital but manual	Digital and automatic	Always and directly accessible
T_3. Interface	Interface characteristics			Client-server	Web-based	Advanced (RIA)
	Device through which it is possible to access the system		There is no BI system	Only through specific devices	All desktop devices	All mobile devices
T_4. User profiling	Profiling level of BI users		No profiling	Macro-area profiling	Single user profiling	Context-based profiling
T_5. Technological integration	Integration with internal systems (automatic data alimentation)		None	Integration with less than 50% of systems	Integration with less than 85% of systems	Integration with more than 85% of systems
	Integration with external systems**		Manual	Mono-directional	Manual bi-directional	Automatic bi-directional
T_6. Standards	Usage of interoperability standards by the BI system		No standards used by the BI applications	Standards for less than 50% of BI applications	Standards for less than 85% of BI applications	Standards for more than 85% of BI applications
	Number of interoperability standards supported		No standards	Only one standard	Few standards	The majority of standards
T_7. Data provisioning	Level of data granularity of inbound data**	Economic Production Qualitative	None or organization	Unit or ward	Event or cure episode	Treatment procedure
	Frequency**	Economic Production Qualitative	Quarterly	Monthly	Weekly or daily	Real time

** Some metrics (e.g,. the quality of reporting) have sub-metrics reflecting the different domains in which the metric can be measured (e.g., economic, production or qualitative data); in these cases, the maturity levels reported in the table are valid for each sub-metric*

*** The maturity levels for this metric/sub-metric are considered achieved by the healthcare organization only if it is valid in more than 50% of cases; for example, a healthcare organization is at level 2 of maturity for the quality of reporting only if in more than 50% of cases its BI system has static reporting with tools for graphic data visualisation; if the BI system provides these tools only in 30% of cases the healthcare organization achieves a maturity level of 1 (static reporting); for more info., see the "prevalence logics" in §4.1*

Table A.2. Components, metrics, and maturity levels in the technological area

TABLE A.3

Component	Metric	Sub-metric*	Maturity levels			
			Level 1	**Level 2**	**Level 3**	**Level 4**
D1. Accessing users	Administrative realm	Directors	Less than 50% of directors	Between 50% and 70% of directors	Between 70% and 90% of directors	More than 90% of directors
		Other users	Less than 25% of users	Between 25% and 50% of users	Between 50% and 75% of users	More than 75% of directors
	Clinical realm	Directors	Less than 50% of directors	Between 50% and 70% of directors	Between 70% and 90% of directors	More than 90% of directors
		Physicians Nurses Other users	Less than 25% of users	Between 25% and 50% of users	Between 50% and 75% of users	More than 75% of directors
D2. System users	Administrative realm	Directors	The system does not trace its use	Less than 50% of users	Between 50% and 75% of users	More than 75% of directors
		Other users	The system does not trace its use	Less than 25% of users	Between 25% and 50% of users	More than 50% of directors
	Clinical realm	Directors	The system does not trace its use	Less than 50% of users	Between 50% and 75% of users	More than 75% of directors
		Physicians Nurses Other users	The system does not trace its use	Less than 25% of users	Between 25% and 50% of users	More than 50% of directors
D3. Process coverage	Administrative realm	General accounting**	None	One or two	Three	All
		Management accounting**	None	One or two	Three	All
		Purchasing**	None	One or two	Three	All
		Logistics and warehouse**	None	One or two	Three	All
		Human resources**	None	One or two	Three	All
		Information systems**	None	One or two	Three	All
		Other processes**	None	One or two	Three	All
	Clinical realm	Emergency room**	None	One or two	Three	All
		Admission, discharge, transfers**	None	One or two	Three	All
		Outpatient, inpatient**	None	One or two	Three	All
		Operating rooms**	None	One or two	Three	All
		Laboratory**	None	One or two	Three	All
		Imaging**	None	One or two	Three	All
		Community care**	None	One or two	Three	All
		Other processes**	None	One or two	Three	All

** Some metrics (e.g., the accessing users in the admin. realm) have sub-metrics reflecting the different domains in which the metric can be measured (e.g., economic, production or qualitative); in these cases, the maturity levels reported in the table are valid for each sub-metric*

*** Process coverage reflects how many of the four functional areas characterising the BI process (goal definition, measurement, gap analysis and decision making) are covered by the BI system*

Table A.3. Components, metrics, and maturity levels in the diffusional area

TABLE A.4

Component	Metric	Sub-metric*	Maturity levels			
			Level 1	Level 2	Level 3	Level 4
O_1. BI strategy	Presence of a BI strategy	Economic Production Qualitative	No strategy	Local strategies	Corporate strategy	The BI lead the change management
O_2. BI budget	Average annual percentage of ICT OPEX delivered to BI in the last 3 years**		Less than 1%	Between 1% and 3%	Between 3% and 7%	More than 7%
	Average annual percentage of ICT CAPEX delivered to BI in the last 3 years**		Less than 1%	Between 1% and 3%	Between 3% and 7%	More than 7%
O_3. Organizational coverage	Dedicated resources	Administrative realm	No internal BI resources	BI resources but not dedicated	Dedicated BI resources	Ad hoc unit
		ICT direction	No internal BI resources	BI resources but not dedicated	Dedicated BI resources	Ad hoc unit
		Clinical realm	No internal BI resources	BI resources but not dedicated	Dedicated BI resources	Ad hoc unit
	Coverage of specific procedures for BI		Null	Only some aspects	Most tech. and operational aspects	Ad hoc unit for definition and control
O_4. Key-user capabilities	Experience of key users		There are no key users	Key users with tech.-only capabilities	Key users with process capabilities	Key users able to anticipate users' needs/problems
	Training programs		No training activities	Sporadic and focused on tech. issues	Sporadic and focused on all BI issues	Continuative and focused on all BI issues
O_5. User capabilities	Administrative realm	Directors	No capabilities	Interpretation of static reports	Management of dynamic reports	Sophisticated "pull" analyses
		Other users	No capabilities	Interpretation of static reports	Management of dynamic reports	Sophisticated "pull" analyses
	Clinical realm	Directors	No capabilities	Interpretation of static reports	Management of dynamic reports	Sophisticated "pull" analyses
		Physicians	No capabilities	Interpretation of static reports	Management of dynamic reports	Sophisticated "pull" analyses
		Nurses	No capabilities	Interpretation of static reports	Management of dynamic reports	Sophisticated "pull" analyses
		Other users	No capabilities	Interpretation of static reports	Management of dynamic reports	Sophisticated "pull" analyses
O_6. Competence improvement	Training programs in the administrative realm	Directors	No training activities	Transferring the importance of BI	Ad hoc to solve specific issues	Continuous training
		Other users	No training activities	Transferring the importance of BI	Ad hoc to solve specific issues	Continuous training
	Training programs in the clinical realm	Directors	No training activities	Transferring the importance of BI	Ad hoc to solve specific issues	Continuous training
		Physicians	No training activities	Transferring the importance of BI	Ad hoc to solve specific issues	Continuous training
		Nurses	No training activities	Transferring the importance of BI	Ad hoc to solve specific issues	Continuous training
		Other users	No training activities	Transferring the importance of BI	Ad hoc to solve specific issues	Continuous training
O_7. Partner/ supplier coordination	Coordinating mechanisms with BI suppliers		No coordinating mechanisms	SLAs limited to ICT topics	Continuous improvement SLAs	BI performance management system and KPIs
	Role of partners and suppliers		No role in managing BI	Reactive involvement for tech.-only issues	Reactive involvement for operating issues	Proactive and innovation-oriented

** Some metrics (e.g., the presence of a BI strategy) have sub-metrics reflecting the different domains in which the metric can be measured (e.g., economic, production or qualitative); in these cases, the maturity levels reported in the table are valid for each sub-metric*

*** We asked for an average percentage of expenditure to avoid any potential fluctuation in BI budget linked to contingent events*

Table A.4. Components, metrics, and maturity levels in the organizational area