Co-developing a Roadmap towards Precision Medicine: Measuring the Maturity of BI in Healthcare

Sina Lessanibahri*

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

Luca Gastaldi
Department of Management, Economics and Industrial Engineering
Politecnico di Milano, Via Lambruschini, 4/B, 20156 Milano,Italy

Astrid Pietrosi

Istituto Mediterraneo per i Trapianti e Terapie ad Alta Specializzazione (ISMETT),Italy

Mariano Corso

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

** Corresponding author*

Structured Abstract

Business Intelligence (BI) has the potential to disrupt the processes through which healthcare services are offered by healthcare agents. Despite this key role, most healthcare organisations fail in 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 suggesting the priorities to be followed in the progressive development of a BI solution. 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 organisations; (ii) enable extensive processes of benchmarking and continuous improvement.

Purpose – To enable extensive processes of benchmarking and continuous improvement in healthcare organisations.

Design/methodology/approach – In order to accomplish the paper's goals we built upon a Clinical Inquiry Research, a well-defined collaborative form of research.

Originality/value – we captured 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 for successfully extending BI solutions to larger domains.

Practical implications – The development of the BI maturity model and the relative assessing questionnaire, which are specific for the healthcare industry.

Keywords – Healthcare, Business Intelligence, Maturity Model.

Paper type – Academic Research Paper

1 Introduction

Nowadays, healthcare is a complicated, knowledge-based industry. The implementation of digital solutions developed large amount of clinical and administrative data, which—if well used through the proper use of BI—allow healthcare organizations to improve both the financial efficiency and the quality of their services (Brooks, et al., 2013).

Davenport and Harris (2006) define BI as a set of technologies and processes that use data, statistical and quantitative analysis, explanatory and predictive models, and fact-based management that, on the one hand, drive decisions and actions, while, on the other hand, enable an accurate understanding of business performance. BI solutions help decision-makers by providing practical information in the right form, right time and right place (Negash, 2004).

The field of BI has improved significantly over the past years (Kohavi et al., 2002), and has promising applications in the healthcare domain (Vercellis, 2009).Despite these potential benefits, many healthcare organizations have not yet implemented BI systems, and there has been very limited research on the factors that contribute to the successful implementation of BI in a healthcare-specific context (Foshay and Kuziemsky, 2014) and the existing BI maturity models do not include peculiarities of particular sectors such as healthcare (Brooks et al 2015).

In fact, most healthcare organisations fail in extending BI suites from the pilot niches in which these digital solutions are usually developed and tested to larger domains (Kohavi et al., 2002). Healthcare practitioners lack comprehensive models suggesting the priori-ties to be followed in the progressive development of a BI solution (Chen et al., 2012).

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 organisations;
- To enable extensive processes of benchmarking and continuous improvement.

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

2 Theoretical Background

We have organised the theoretical background of the paper into two sessions. The first proposes the latest development in the field of healthcare BI, and reveals the lack of

models and tools to support BI in rendering as salient their disrupting potential. The second focuses on maturity models, and on their core elements and the logic through which maturity models are developed.

2.1 Business Intelligence in Healthcare

Healthcare organizations are under increasing pressure to do more with less and are continually seeking ways to ensure that resources are deployed as efficiently as possible while ensuring high quality patient care (Gastaldi and Corso, 2012). BI is essential to meet these goals (Pine et al., 2012) since it progressively takes healthcare agents along the continuum from intuitive to empirical and ultimately to precision medicine (Christensen et al., 2009).

Foshay and Kuziemsky (2014) contend that improper implementation of BI in healthcare organization and/or lack of organizations readiness result in lack of confidence in mangers' decisions and increase the time required to make decisions. To avoid these adverse impacts, they suggest to reflect on identifying the information needs of core processes in the healthcare organizations.

While studies of BI in healthcare exist (e.g., Ferrand et al., 2010; Tremblay et al., 2012), they have put limited emphasis on the process and tools through which BI systems have to be developed in order to accelerate this transition. Most studies have highlighted some key elements without putting them into a coherent and comprehensive framework.

Ramamurthy et al. (2008) view BI implementation success as dependent upon organizational factors such as management commitment, organization size and absorptive capacity, as well as characteristics of the BI system, including relative advantage and low complexity. Isik et al. (2011) contend that successful BI implementations require specific capabilities including high quality data, appropriate user access and effective integration with other systems.

Popovic et al. (2012) measure BI maturity in terms of data integration effectiveness and analytic capabilities. Starting from similar premises, Sen et al. (2012) propose a five-stage maturity model covering both the development and on-going operations of BI systems. However, their tool is not effective in providing practitioners with actionable knowledge to support the development of effective roadmaps for their BI systems. Moreover, the model does not consider the idiosyncrasies of the healthcare industry.

2.2 Maturity Models

Maturity models have their roots in the field of quality management (Chiesa et al., 1996). The concept of maturity implies an evolutionary progress from an initial to a desired target or naturally existing end stage (Marx et al., 2012). The notion of evolution is implicit in the stages of growth, suggesting that the progress transitions through a number of intermediate states on the way to higher maturity levels (Sen et al., 2012). In the information systems discipline, maturity is regarded as "a measure to evaluate the capabilities of an organisation" (Rosemann and De Bruin 2005). Maturity models

facilitate this evaluation by outlining anticipated, typical, logical, and desired evolution paths (Becker et al., 2009).

In response to criticism of missing methodical foundations and insufficient comparability (Biberoglu and Haddad 2002), researchers in the field of maturity levels mostly focus on their foundations (e.g., Becker et al., 2010), e.g., classification schemes, construction methods and design principles. In terms of model elements, the key ones are (Marx et al., 2012):

- *Dimensions*: specific capability areas, process areas, or design objects structuring the field of interest. They should be exhaustive and distinct. Each dimension is further specified by a number of measures or by qualitative descriptions for each maturity level.
- *Levels*: archetypal states of maturity of a certain dimension or domain. Each level should have a descriptor clearly providing the intent of the level and a detailed description of its characteristics. These characteristics should be distinct and empirically testable while the relationship of each level to its predecessor and successor should be well defined.

3 Research Methodology

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

- The ISMETT, an highly-digitalised hospital (656 employees, 86 beds) in Italy that has won an award for its BI solution[1];
- Five other hospitals representative of the variety of the Italian healthcare industry and with experience in the development of BI solutions.

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

CIR is a well-defined collaborative form of research developed by Schein (2008). A distinguishing characteristic of CIR is in the setting of the activity (Coghlan and Brannick, 2005).

In order to develop a model for assessing the maturity of the BI system a Research Task Force (RTF) was formed in November 2012. According to leading literature on collaborative research (Mohrman and Mohrman, 2004), 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 (Womack and Jones, 2003), face-to-face interviews and multi-participant interactive dialogues (Mikaelsson and Shani, 2004) were the main collaborative mechanisms utilized.

[1] *ISMETT is born thanks to a joint public-private partnership between the Region of Sicily (through Civico and Cervello hospitals in Palermo) and UPMC, an integrated global health enterprise headquartered in Pittsburgh, and one of the leading not-profit health systems in the United States.*

3.1 BI Maturity Model Development

Given the complexity of the model to be created, its development necessitated the design of intermediate constructs (Sen et al., 2012). First, we performed an extensive literature analysis to understand not only the different metrics through which to assess the maturity of the BI solution, but also potential ways of grouping these metrics in mutually exclusive areas of development. This exercise allowed the production of a preliminary version of the BI maturity model, which the RTF progressively discussed and refined.

Information acquisition and knowledge systematisation were accomplished in multiple modes—depending on the specific intent, of the specific stage of model elaboration and on the experience developed. Initially, brainstorming sessions (McGraw and Harbison-Briggs, 1989) were used within the RTF to elicit ideas for model conceptualization. The objectives of this phase were to assess the potential value of a maturity model, and to identify the different areas and components characterising 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 (Sen et al., 2012), 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 classifications for the areas, as well as on the components and metrics characterising 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 (McGraw and Harbison-Briggs, 1989) 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 main key areas of the BI models have been identified (Sen et al., 2012).

Acting as a process facilitator, the researchers supported ISMETT in the definition of 119 metrics to assess the maturity of BI solutions in healthcare settings. These metrics have been subdivided into 23 components, which have been grouped into four different areas, namely Functional, Technological, Diffusional and Organisational.

For each metric, the RTF identified a question with four alternative answering options, which 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 organisations involved into the CIR project. Specifically, we conducted multiple interviews to analyse, and understand if 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.

3.2 BI Maturity Model Application

One approach for assessment of the model is through interviews with leaders and stakeholders of the organization (Brooks, 2015). Thus, after the validation of the model, the RTF presented it to ISMETT's leadership, which asked the researchers to help it assess the maturity of its BI solution, and—starting from this assessment—to co-define a roadmap for fully exploiting BI.

It is important to note that, for each metric, we asked the informants not only to evaluate the current (April 2013) maturity levels achieved in 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 of 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 systematising in a unique and coherent framework:

- The different interventions planned by the hospital for each area of the model (derived from a joint reflection over ISMETT's position in the BI maturity model);
- Some critical issues that were core for achieving the expected levels of maturity (derived partially from analysis of the literature and partially from an analysis of other healthcare organisations that were developing a BI solution[1]);
- Further evolutions that could be interesting to accomplish for making the BI solution as synergic as possible to 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, but recognised that these stimuli were not sufficient to develop a roadmap allowing a real prioritisation of the different interventions and investments. Starting from this consideration, the RTF organised some meetings through which to reflect on the different relationships among the components (and, thus, metrics) characterising the model. To ensure reliability (Bourgeois and Eisenhardt, 1988) all meetings were facilitated by two researchers, recorded, transcribed and coded.

A cross-analysis of all meetings allowed the researchers to propose a preliminary version of a framework of interdependencies (necessity of a prioritisation in the development) and synergies (necessity of 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 (Mikaelson and Shani, 2004) and converged on a final version that was reviewed and then validated

[1] *From this viewpoint, the RTF leveraged on the assets of an Observatory that is coordinated by the last author of this paper. Please, refer to Gastaldi and Corso (2013) for a description of the Observatory.*

by the BI experts, managers and users in the other five hospitals involved into the CIR project.

Finally, we linked the framework to the maturity levels of the various components of the BI model in order to determine different clusters of components to be prioritised. To accomplish this task, we: (i) averaged the maturity levels of the different metrics characterising each component; (ii) translated the various prerequisites and synergies of each component into a comprehensive value, calculated according to a predefined set of scores[1]; (iii) checked the consistency of the results in the RTF; (iv) presented them to the BI experts at ISMETT to collect their feedback; (v) validated the different clusters of component prioritisation.

4 Findings

We have organised this paragraph according to the different outputs achieved during the CIR project. First, we present the BI maturity model and the questionnaire through which is possible to assess a generic healthcare organisation over that model (see §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 §4.2); (ii) provide useful elements for developing an action plan to be followed in order to increase the maturity and, thus, the effectiveness of its BI solution (see §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 organised in developmental areas, components and metrics. For each metric, 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., goal definition 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.

The questionnaire is organised into five sections. The first section asks for general information related to the healthcare organisation answering the questionnaire (e.g., number of departments, beds, employees) and its information system (e.g., number of workstations, ICT partners/suppliers, reports produced through the BI system). The ideas were to:

- Obtain descriptive variables allowing a characterisation of the context in which the company is inserted to cluster the healthcare organisations answering the questionnaire;
- Collect useful quantitative data to better understand and interpret the answers given by each healthcare organisation answering the questionnaire.

[1] *4 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.*

The remaining four sections focus on the developmental area individuate in §3.1. For each metric and/or sub-metric, the RTF produced a question with four alternative answering options that reflect the increasing levels of maturity of the BI solution.

4.2 Assessment of Actual and Expected BI Maturity

The assessment of ISMETT on the BI maturity model allowed supporting 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 not that developed, and were expected to be improved in the three years following the assessment exactly to fill the gaps with technological maturity. This is coherent with what is suggested by both the literature (e.g., Sen et al., 2012) and the practitioners involved into 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 characterising 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 crossed or approached the level 3 of maturity.

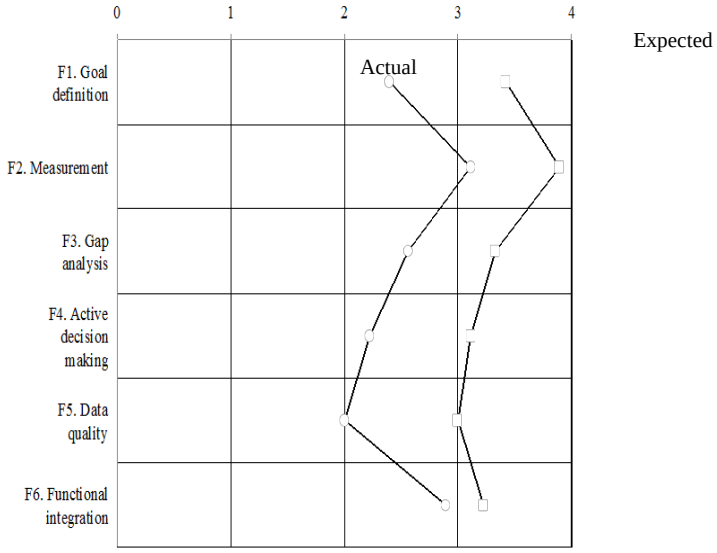

Figure 1. ISMETT position on the functional components of the BI maturity model

4.3 Supporting the Development of a Roadmap toward Precision Medicine

One of the main limits of the other maturity models in the literature is that the relationships among the different metrics and components are often tacit (Marx et al., 2012). In the spirit of tackling this issue, the RTF produced Figure 2, which, considering two components X and Y of the model, allowed us to identify four different relationships between them:

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

The figure provides a healthcare organisation aiming to increase the maturity of its BI solution with important information to lead each intervention/investment. A vertical analysis of the table emphasises the prerequisites and the interdependencies necessary and/or suggested to increment the maturity of a component. For instance, 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 equal to 2.22, and expected to achieve a level of 3.11 in the next three years. To realise 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 support 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 realising this improvement.

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—emphasising the components that have the highest priority due to the fact that they are a strong prerequisite of many other components.

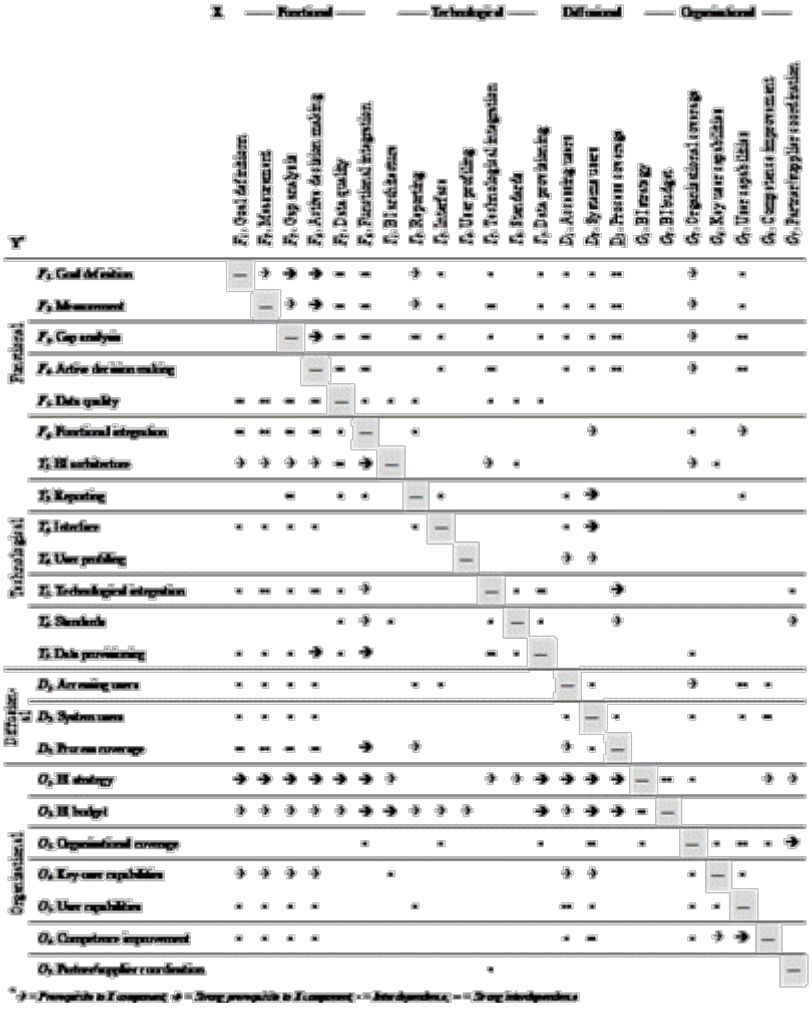

Figure 2. Interdependencies and synergies among the components of the BI maturity model

In order to develop a specific and effective action plan and to homogenize the maturity level of various components, we prioritize the further improvement of the components. Starting from Figure 2, we translated the various prerequisites and synergies of each component into a comprehensive value. Consider two components Y_j and X_j where Y_j is a perquisite (or there is synergy) of X_j. To prioritize the development of components, a score is assigned to each component Y_j based on the Equation 1. The higher values of the assigned score indicate immediate investment or focus on the component.

$$\boldsymbol{Score\ Y_j = \sum_{i=1}^{n}\left[\left(EM_{X_i} - AM_{X_i}\right)\frac{1}{AM_{X_i}}\frac{\left(PS_{Y_jX_i} - AM_{Y_j}\right) + \left|PS_{Y_jX_i} - AM_{Y_j}\right|}{2}\right]} \qquad \forall\, \boldsymbol{j = 1 \ldots n}$$

Eq. 1

Where:

$\boldsymbol{n}$: *number of components*

$\boldsymbol{Score\ Y_j}$: *overal score given to component* Y_j,

$\boldsymbol{EM_{X_i}}$: *expected maturity of component* X_i *in future*

$\boldsymbol{AM_{X_i}}$: *current maturity of the component* X_i

$\boldsymbol{PS_{Y_jX_i}}$: *number of points given based on the relationship(prequisite or interdependency) between* Y_j *and* X_i

The first part of the Equation 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 invert 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 is 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 maturity needed to develop X_i, this coefficient is positive otherwise, it is zero. For instance if the component Y_j is perquisite 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 3 depicts the calculated scores of BI components of ISMETT. As it is shown in the figure, BI budget, BI strategy and process coverage are the first three areas that need more attention and/or investment.

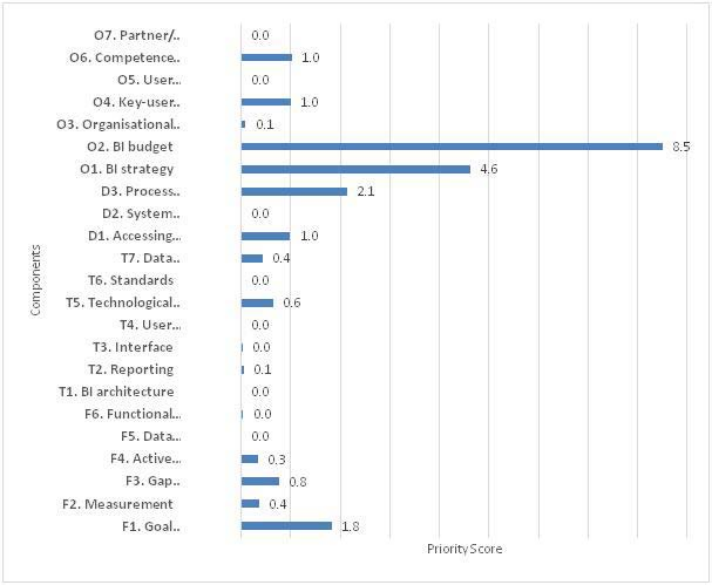

Figure 3. Priority score of components for healthcare BI at ISMETT

5 Conclusions

Besides the actual support to ISMETT in increasing the maturity of its BI solution, the main contribution of this study is the development of two artifacts—the BI maturity model and the relative assessing questionnaire—which are specific for the healthcare industry and allow to effectively address the pressing issues associated with BI solutions within it.

The research showed that the development of a BI solution is essentially an evolutionary process, and that is possible to identify several discrete stages on the roadmap toward a full exploitation of BI in the realisation of precision medicine. We proposed that an immature BI system could be a major reason behind the failure of so many BI initiatives, and we captured 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 for successfully extending BI solutions to larger domains.

Moreover, activating organization-wide processes of involvement, the artifacts described in this paper allow 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 benchmarking regarding the strategies through which different healthcare organisations develop a BI solution, but also represent useful tools for understanding which components to focus on in a healthcare organisation in order to progressively make its BI solutions more efficient and effective—providing scope for continuous improvement.

We envision couple of streams of research emerging out of our work. Following the software process maturity paradigm (Krishnan and Kellnes, 1999), the first stream would focus on organizational attempts at characterising 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 for 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 continuous process improvement, will streamline BI project management and substantially improve the productivity and data quality of BI solutions.

Another 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 would be 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 production of homogenizing policies and continuous improvement strategies at a regional level.

References

Becker J., Knackstedt R., Pöppelbuß J. (2009) Developing Maturity Models for IT Management: A Procedure Model and its Application, *Business and Information Systems Engineering*, Vol. 1, No. 3: pp. 13–22.

Becker J., Niehaves B., Pöppelbuss J., Simons S.A. (2010) Maturity Models in IS Research, *18th European Conference on Information Systems* (ECIS), Pretoria.

Biberoglu E., Haddad H. (2002) A Survey of Industrial Experiences with CMM and the Teaching of CMM Practices, *Journal of Computing Sciences in Colleges*, Vol. 18, No. 2, pp. 143–152.

Bourgeois L.J., Eisenhardt K.M. (1988) Strategic Decision Processes in High Velocity Environments: Four Cases in the Microcomputer Industry, *Management Science*, Vol. 34, No. 6, pp. 816–835.

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, Vol. 35, No. 3, pp. 337–345.

Brooks, P., El-Gayar, O.,Sarnikar, S. (2013). Towards a Business Intelligence Maturity Model for Healthcare. In System Sciences (HICSS), 2013 46th Hawaii International Conference on (pp. 3807-3816). IEEE.

Chen H., Chiang R.H.L., Storey V.C. (2012) Business Intelligence and Analytics: From Big Data to Big Impact, *MIS Quarterly*, Vol. 36, No. 4, pp. 1165–1188.

Chiesa V., Coughlan P., Voss C. (1996) Development of a Technical Innovation Audit, *Journal of Product Innovation Management*, Vol. 13, No. 2, pp. 105–136.

Christensen C.M., Grossman J.H., Hwang J. (2009) *The Innovator's Prescription: A Disruptive Solution for Health Care*, New York (NY): McGraw–Hill.

Crist-Grundman D., Mulrooney G. (2011) Effective Workforce Management Starts with Leveraging Technology, *Nursing Economics*, Vol. 29, No. 4, pp. 195–200.

Coghlan D., Brannick T. (2005) *Doing Action Research in Your Own Organization*. London (UK), Sage.

de Bruin T., Rosemann M., Freeze R., Kulkarni U. (2005) Understanding the Main Phases of Developing a Maturity Assessment Model, *16th Australasian Conference on Information Systems (ACIS)*, Sydney

Davenport T.H., Harris J.G. (2006) *Competing on Analytics: The New Science of Winning*, Boston (MA): Harvard Business School Press.

Ferrand D., Amyot D., Corrales C.V. (2010) Towards a Business Intelligence Framework for Healthcare Safety, *Journal of Internet Banking and Commerce*, Vol. 15, No. 3, pp. 1–9.

Foshay N., Kuziemsky C. (2014) Towards an Implementation Framework for Business Intelligence in Healthcare, *International Journal of Information Management*, Vol. 34, No. 1, pp. 20–27.

Gastaldi L., Corso M. (2012) Smart Healthcare Digitalization: Using ICT to Effectively Balance Exploration and Exploitation Within Hospitals, *International Journal of Engineering Business Management*, Vol. 4, Special Issue on Digital and Mobile Economy, pp. 1–13.

Gastaldi L., Corso M. (2013) Academics as Effective Orchestrators of Interorganizational Change and Development, in: Pasmore W., Woodman R., Shani A.B. (Rami), Noumair D.A. (Eds.) *Research in Organizational Change and Development (Vol. 21)*, Bingley (United Kingdom): Emerald, pp. 59–119.

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*, Vol. 16, No. 4, pp. 14–30.

Isik O., Jones M.C., Sidorova A. (2011) Business Intelligence (BI) Success and the Role of BI Capabilities, *Intelligent Systems in Accounting, Finance and Management*, Vol. 18, No. 4, pp. 161–176.

Kohavi R., Rothleder N.J., Simoudis E. (2002) Emerging Trends in Business Analytics, *Communication of the ACM*, Vol. 45, No. 8, pp. 45–48.

Krishnan M.S., Kellner M.I. (1999) Measuring Process Consistency: Implications for Reducing Software Defects, *IEEE Transactions on Software Engineering*, Vol. 25, No. 6, pp. 800–815.

Levie J., Lichtenstein B.B. (2009) Final Assessment of Stages Theory: Introducing a Dynamic States Approach to Entrepreneurship, *College of Management Working Papers*.

Marx F., Wortmann F., Mayer J. (2012) A Maturity Model for Management Control Systems, *Business and Information Systems Engineering*, Vol. 4, No. 4, pp. 193–207.

McGraw K.L., Harbison-Briggs K. (1989) *Knowledge Acquisition*, New York (NY): Prentice-Hall.

Mikaelsson J., Shani A.B. (2004) Rethinking and Transforming Product Development, in: Adler N., Shani A.B., Styhre A. (Eds.) *Collaborative Research in Organizations*, Thousand Oaks: Sage, pp. 181–196.

Mohrman A.M.Jr., Mohrman S.A. (2004) Self-designing a Performance Management System, in: Adler N., Shani A.B. (Rami), Styhre A. (Eds.) *Collaborative Research in Organizations: Foundations for Learning, Change, and Theoretical Development*, Thousand Oaks (CA): Sage.

Negash, S. (2004). Business intelligence. The Communications of the Association for Information Systems, Vol. 13, No. 1, pp. 54.

Pine M., Sonneborn M., Schindler J., Stanek M., Maeda J., Hanlon C. (2012) Harnessing the Power of Enhanced Data for Healthcare Quality Improvement: Lessons from a Minnesota Hospital Association Pilot Project, *Journal of Healthcare Management*, Vol. 57, No. 6, pp. 406–418.

Popovic A., Hackney R., Coelho S., Jaklic J. (2012) Towards BI Systems Success: Effects of Maturity and Culture on Analytical Decision Making, *Decision Support Systems*, Vol. 54, No. 1, pp. 729–739.

Ramamurthy K., Sen A., Sinha A.P. (2008) An Empirical Investigation of the Key Determinants of Data Warehouse Adoption, *Decision Support Systems*, Vol. 44, No. 4, pp. 817–841.

Rosemann M., De Bruin T. (2005) Towards a Business Process Management Maturity Model, *13th European Conference on Information Systems (ECIS)*, Regensburg.

Sen A., Ramamurthy K., Sinha A.P. (2012) A Model of Data Warehousing Process Maturity, *IEEE Transactions on Software Engineering*, Vol. 38, No. 2, pp. 336–353.

Schein E.H. (2008) Clinical Inquiry/Research, in: Reason P., Bradbury H. (Eds.) *The SAGE Handbook of Action Research: Participative Inquiry and Practice*, Thousand Oaks (CA), SAGE, pp. 266–279.

Tremblay M., Hevner A., Berndt D. (2012) Design of an Information Volatility Measure for Health Care Decision Making, *Decision Support Systems*, Vol. 52, No. 2, pp. 331–341.

Vercellis C. (2009) *Business Intelligence*, West Sussex (UK): Wiley.

Womack J.P., Jones D.T. (2003) *Lean Thinking*, New York (NY): Simon and Schuster.

Appendix

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 organisation	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 organisation	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 organisation	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. Active decision making	Level of data granularity**	Economic Production Qualitative	None or organisation	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 organisation only if it is valid in more than 50% of cases; for instance, a healthcare organisation 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 active decision making)*

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

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 organisation	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 organisation only if it is valid in more than 50% of cases; for example, a healthcare organisation 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 organisation 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

Component	Metric	Sub-metric*	Maturity levels			
			Level 1	Level 2	Level 3	Level 4
D_1. 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
D_2. 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
D_3. 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 active decision making) are covered by the BI system*

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

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. Organisational 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 organisational area