Interoperability Assessment in Healthcare Based on the AHP/ANP Methods

Victor Scuissiatto(✉), Eduardo Alves Portela Santos, Eduardo Rocha Loures, Sarah Bueno, and Vanessa Santos

Pontifical Catholic University of Paraná - PUCPR/PPGEPS, Imaculada Conceição Street, 1155 – Technological Park – Block 3, Curitiba, PR 80215-901, Brazil
{victor.scuissiatto,eduardo.portela,eduardo.loures, sarah.bueno,vanessa.santos}@pucpr.br

Abstract. Hospitals and other healthcare providers have been using the available technological resources in providing treatments targeted at improving quality for the treatments for citizens. The resulted collaborative environment is characterized by strong process coordination and information management and closely related to the concept of interoperability. The analysis of the different capabilities of the hospitals in terms of interoperability perspectives provides a very appropriate diagnostic tool for actions in improvement of the organizational performance. This kind of assessment can meet in the multi-criteria decision making/analysis (MCDM/A) methods suited approach to analyzing interoperability barriers. This paper investigates the interoperability in the domain of healthcare by deploying the AHP/ANP MCDM/A methods in EIA (Enterprise Interoperability Assessment) background. A conceptual framework is presented to support the development cycle of a proposed EIA structure. The results reveal different frailties in a reference hospital entity under analysis in its domain of action in oncological treatment.

Keywords: Interoperability assessment · Decision making methods · AHP/ANP · Healthcare · Oncology

1 Introduction

Currently, solving complex problems and making assertive decisions in healthcare is essential in an environment that is increasingly more complex and where the access to knowledge and information is fundamental. Providing complete healthcare to patients, promoting operational innovation, assertiveness and excellence, has been a challenge. These performance requirements are closely related to the concept of interoperability, linked to the hospital entity's capability in dealing with the heterogeneous characteristic of the information and with processes coordination supported by heterogeneous information systems and different decision makers. In this way, interoperability enables the definition of metrics to assess a hospital in terms of its interoperation capability or potential to interoperate. This understanding corroborates with the interoperability definition – the capacity of two or more systems of exchanging information and the

Á. Rocha et al. (eds.), *Recent Advances in Information Systems and Technologies*,
Advances in Intelligent Systems and Computing 569, DOI 10.1007/978-3-319-56535-4_67

subsequent reciprocal deployment, among organizations or within the same organization [1]. Thus, one can infer that, considering the complex hospital environment and the need for the exchange of information through its organizational structure, business rules and process, interoperability assessments can help in mapping and diagnosing barriers with adverse impact on organizational performance. This enterprise assessment founded on interoperability dimensions differs from the known CMMI/SCAPI methods extending the diagnosis capability towards a less subjective maturity positioning as advocated in [2]. Motivated by a lack of specific interoperability assessment approaches in healthcare domain [3], this paper presents an Enterprise Interoperability Assessment (EIA) structure based on a development framework and the multi-criteria AHP/ANP methods. These methods are adequate to organize the assessment knowledge (attributes) into a structure able to characterize different assessment levels and granularities facing the complexity of hospital environments. For that, the perspectives of interoperability and its assessment attributes identified in the healthcare domain, as well as the main interoperability frameworks for this purpose are firstly presented. At the end, the resulting assessment and the diagnosis generated are presented inferring on the interoperability capabilities of a relevant hospital entity in oncological treatment.

2 Interoperability

We can state that in healthcare interoperability is of the utmost importance, a quality assurance in delivering hospital services to individuals in a quick, effective and adequate manner. The healthcare area requires that hospital services display an extremely important characteristic - adequate coordination of processes and efficient exchange of information involving the systems deployed [4]. The capability of two or more systems or components to exchange information and use the information exchanged, as defined in [5], infers that the people involved – interaction agents with these systems, must display understanding from the standpoints of Process and Information. But for an adequate processes coordination and information flow [6, 7], a suitable organizational structure must be provided to allow minimizing barriers that prevent good performance, with a view to optimizing the capacity to interoperate [8].

2.1 Interoperability Frameworks

Literature presents a number of different interoperability framework models for different contexts, with some being specific to the healthcare area [8]. The existing objective is to provide an organizational mechanism in such a way that the interoperability concepts and perspectives within the hospital environment are better structured and represented. To facilitate understanding, one can mention two of the main frameworks in current literature. The **Framework for Enterprise Interoperability (FEI)** – developed by the European Excellence Network, classifies and defines three dimensions: interoperability barriers, interoperability approaches and enterprise interoperability concerns, also called enterprise levels. The interoperability *barriers* are in connection with the removal of obstacles identified in establishing interoperability. Three types of barriers are identified:

(i) *conceptual* nature in connection with syntactic and semantic differences in the information to be exchanged; (ii) *technological* barriers in connection with incompatibility among the information technologies and (iii) barriers of an *organizational* nature, in connection with the organizational and management structures deployed in companies [9]. Interoperability *concerns* are in reference to the diagnostic or establishment of interoperability requirements in companies or hospitals, in covering the different operational levels. Four levels represent the areas related to interoperability concerns: (i) *data* interoperability with reference to the different data models and structures; (ii) *service* interoperability concerned with identifying, composing and execution of the different applications/services (conceived and put in place independently) in solving the syntactic and semantic differences, as well as finding the connections among the different heterogeneous databases; (iii) *process* interoperability with reference to the coordination of the different processes undertaken and (iv) *business* interoperability with reference to the organizational structure, models and business rules [9]. The second relevant framework is the **National EHealth Transition Authority (NEHTA)** – featuring definitions for three perspectives in interoperability focusing on healthcare agencies [4, 5]. The (i) *organizational* perspective includes the aspects of shared information policy and process structures, as well as business rules. This perspective includes the business processes, standards, safety policies and privacy policies. The (ii) *information* perspective remits to shared semantic construction structures with a view to enabling exchange of information [5]. It guides the endeavors in the exchange of fundamental information, domains, structures, common associations, relationships and metadata. The (iii) *technical* perspective is concerned with the connectivity of the information exchange and services use systems. It drives solutions based on open standards offering equality of conditions in competitive delivery of technical solutions [5]. The perspectives and dimensions of these frameworks help in providing the structural specification for the multi-criteria decision analysis methods proposed in this work.

2.2 MCDM/A Methods and Their Applicability in Healthcare

The MCDM/A methods are widely used across a number of different sectors, including healthcare [10, 11]. In modeling a problem for decision (assessment), we can count with one or more decision aid agents and deploy a set of criteria enabling qualifying the entity under assessment. Each decision agent is responsible for defining the personal judgment values for each criteria and the weighting (or pertinence) of the criteria in the decision. In MCDM/A methods, alternatives (in this work meaning capability/potential interoperability levels) are assessed based on a number of previously established criteria, with each one of the criteria inducing to a particular ordering of the alternatives, making it necessary to adopt a mechanism capable of building a general ordering of preferences, also known as ranking or classification [12]. The results produced by these methods should be considered as support for decision-making, exploring the uncertainty in the problem of the decision and assessment. Decision-makers may deliberate on the best evidence and tacit perceptions by providing more adequate scoring, which is then weighted by the assessment method.

In this paper, the methods used are AHP (Analytic Hierarchy Process) and ANP (Analytic Network Process), highly appropriate for assessing domains characterized by uncertainty, tacit knowledge and heterogeneous nature of the assessment knowledge involved, such as the domain of healthcare [10]. The multi-criteria analysis using AHP targets structuring a hierarchical qualitative and relational assessment. The use of AHP starts by breaking the problem down applying a hierarchy of criteria that is more easily comparable and can be analyzed independently [13]. After the establishment of the hierarchy, decision-makers evaluate alternatives (capabilities) by way of pairwise comparison within each one of the criteria. AHP transforms these comparisons following Saaty's scale into numerical values - the weighting, which is defined for each criteria, enables assessing each of the elements within the hierarchy defined. After performing all the comparisons and attribute relative weighting among the criteria to be assessed, the numeric inference of each one of the alternatives is calculated [13] leading to capability/potential interoperability level inferences. ANP - Analytic Network Process – is a special case of the AHP method. While in AHP the alternatives are compared only with respect to a global objective, ANP compares alternatives with respect to different groups of factors and at different levels, creating a more complex comparison network and resulting in more accurate outcomes [13]. ANP preconizes identifying criteria or some criteria with decisive influence on two or more criteria of the same level. These influenced criteria will play the role of alternatives and will be compared pairwise considering the degree of influence that each one has in the overall performance. This way, the weighting obtained through the AHP method will be amended according to the number of additional connections performed.

3 Interoperability Assessment in Healthcare

The interoperability assessment structure in the healthcare domain based on the AHP/ANP methods follows a development cycle supported by a conceptual framework. For a better understanding of this proposed framework, it has been subdivided into nine main stages, which were structured into one IDEF0 diagram [14], appropriate for methodological approach modeling. Fig. 1 shows the different stages. The objective of the **knowledge acquisition** stage, which addresses activities from A0 to A2, is to perform a literature review extracting concepts on healthcare and interoperability assessment frameworks for this domain, having as output the interoperability perspectives, including an interview with specialist to define the knowledge and attributes obtained in the preliminary assessment. The structure called **IIMH** (Interoperability Influence Matrix in Health domain), pillar of the **organizational of knowledge** stage, organizes these attributes under the interoperability perspectives, as well as takes into account the influence relations existing in the assessment spectrum. The next stages, based on IIMH, correspond to the concept and modeling of EIA assessment structures: shown in activities A5, A6 and A7, based on the **AHP Method** and with reference to activities A5, A8 and A9, based on the **ANP Method** that incorporates the influence relations among attributes, modeled by IIMH. A more detailed description of the stages and its components is given next.

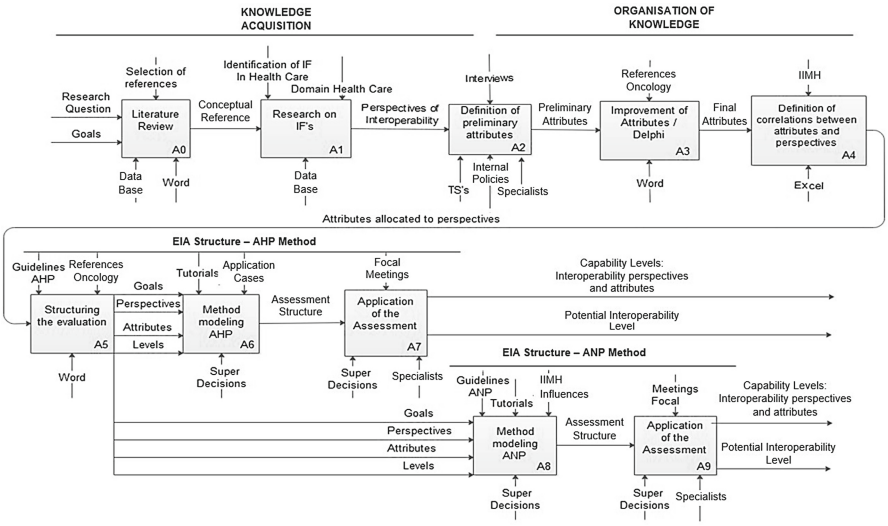

Fig. 1. IDEF0 development framework.

3.1 Knowledge Acquisition stage

The baseline reference used in obtaining the attributes for assessment in the healthcare domain, in the specialized context of cancer treatment (area of activity of the entity under assessment), was the study by Salmon [15] "*Oncology Networks: Best Practices - A Study of Governance, Resources and Clinical Coordination*". This study provided a manual of good practices and some of the more advanced structures in the area of oncology, considering the standards to be followed and applied in all hospital and clinic environment delivering oncology treatment services. After obtaining the consensual perception of the specialists on the assessment knowledge, 25 attributes were listed, treated and validated for the context based on instrumental mechanisms called the Task Sheet [16] and the Delphi Method. These attributes are organized under the perspectives in interoperability inspired in the FEI and NEHTA frameworks, previously shown: (i) *Business*, (ii) *Process Management*, (iii) *Policy and Procedures*, (iv) *Human Resources*, (v) *Information Technology*, (vi) *Semantics*. This organization is related to the Organization of Knowledge stage (activities A0, A1, A2, Fig. 1).

3.2 Organization of Knowledge stage

In order to organize the attributes raised in the interoperability perspectives and their relational analysis, the IIMH structure (Interoperability Influence Matrix in Health domain), inspired in QFD (Quality Function Deployment) [17], is proposed and shown in Fig. 2. In IIMH, columns correspond to the assessment attributes and the lines to the six perspectives of interoperability. This way, scores (1, 3, 6 or 9) were attributed to each attribute, according to the degree of correlation between the attribute and the perspective under analysis. In the end, in each perspective, the attributes with the highest

scores for the aspect under consideration were allocated, with one attribute, in some cases, being allocated to up to 2 perspectives. The weighting placed in the upper triangular region refer to the influence relations existing among the attributes raised, enabling the fine-tuning of the assessment structure modeled by the ANP method. The scores are obtained by the experts' perceptions (physician, practitioner and health service managers) and corroborated by complementary sources of information as the Task Sheets [16], internal policies and data-logs from Information Systems submitted to Process Mining techniques in order to reveal influence relations [18]. It is important to note that these scores and the IIMH is devoted to assist the design of the AHP/ANP structures but not to the assessment itself.

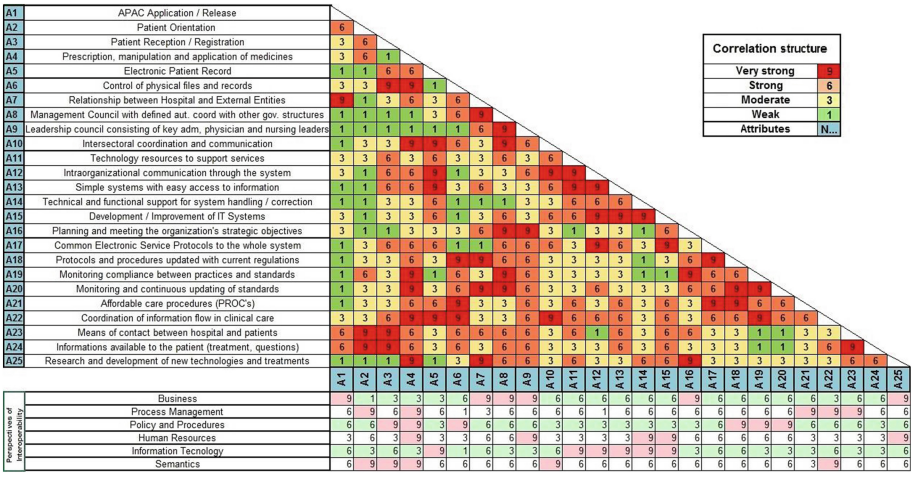

Fig. 2. IIMH structure.

3.3 EIA Structure stage - AHP and ANP Methods

Structuring the knowledge involved in assessing interoperability within the healthcare domain, specializing in oncology treatment, promoted by IIMH, enables the development of the AHP structure shown in Fig. 3. The attribute and interoperability perspectives relational matrix (bottom of Fig. 2) infer on the AHP hierarchical structure; the influence relations (top of Fig. 2) extend the structures to the ANP model. Following the AHP structure the "Interoperability Assessment" represents the level 1 and the objective of the assessment; the six interoperability perspectives (categories) represent level 2; the twenty-five attributes organized in these perspectives represent level 3; the capability levels are located on the last level. At each level and category (clusters), pairwise assessment and priority vector definition matrixes are characterized on the basis of AHP method (Sect. 2.2). The matrix inference of all the performed partial AHP priority vectors (upper levels) results the interoperability potential assessment for the hospital agency in providing cancer treatments and corresponds to the last (lower) AHP

level. The attributes in bold (Fig. 3) are examples of influence relations (indicated by arrows) stemming from IIMH (highest weighting) in characterizing an ANP structure.

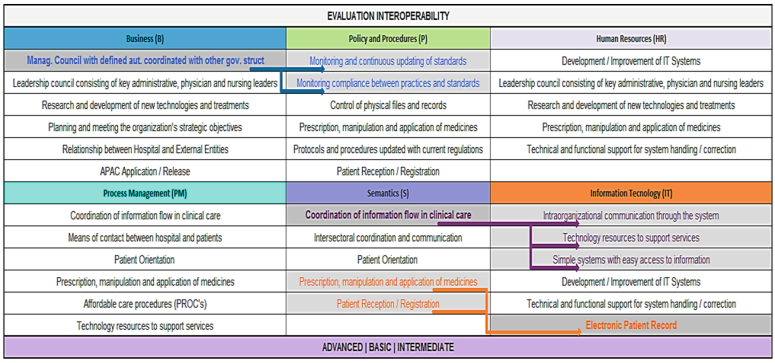

Fig. 3. AHP/ANP structure.

3.4 Potential Interoperability Levels in Organizational Assessment

In order to define the levels of interoperability assessment, which represent the final alternatives in the AHP structure, bibliography surveys were carried out for the purpose of finding a suitable and appropriately based assessment levels. The related scale found and considered pertinent to the context was adapted based on studies performed by Salmon [15], and addressed three levels. The *Basic Level* characterizes a major variation in the processes and practices applied, with a significant dependence on manual, complex and time-consuming systems. In the *Intermediate Level* institutions endeavor to achieve a wide range of organizational objectives, including the reduction in internal process variability and higher levels of integration among the departments; these are networks characterized by complex processes or systems, but under coordination of a central council or agency. In the *Advanced Level,* networks feature a completely developed structure, with strategically defined policies and resources in order to deliver the network's organizational objectives; they develop consistent and effective processes with a view to obtaining satisfactory outcomes in the service delivery points; these institutions are continually expanding their oncological assistance, with innovative initiatives and establishing partnerships with groups of interest external to the network, such as National Health Institute [15].

4 Application Case and Results

The interoperability assessment was undertaken in a cancer treatment reference hospital in southern Brazil that addresses over 1000 patients a day. Due to the complexity and size of the hospital in terms of the volume of information traffic among the different processes, the critical path of the oncology sector was identified for assessment purposes [16]. Data collection interviews with process participants, physicians, nurses and health

service managers was carried out on the basis of AHP pairwise relational assessment. The objective is a diagnostic investigation of the entity's different levels of capability under the perspective of interoperability, identifying granularly the existing barriers to better organizational performance in the delivery of cancer treatments processes. At the end, a position for the hospital is inferred in terms of its potential interoperability. The AHP/ANP structure (Fig. 3) was implemented in the Super Decisions platform.

4.1 Results Obtained

Initially, in the AHP assessment model, with the collected data from interviews, the comparison of importance among the pairs of criteria with respect to the main objective was performed and, following that, for the sub-criteria with respect to the immediate superior line criteria. With this data in hand, the weighting (or significance) could be obtained for each of the attributes considered. At the end of the assessment, the comparison among alternatives (levels of potential interoperability) with respect to each sub criteria is performed, resulting in defining a percentage of matching of the attributes in each one of the levels considered.

As a general outcome for the AHP method, the following percentages of the potential interoperability level for the hospital entity in the delivery of cancer treatment were obtained: 18.10% at the advanced level, 21.92% at the basic level and 59.97% at the intermediate level, as shown in Fig. 4(A). The deployment of the assessment using the ANP method also had participation of specialists, being performed based on the additional comparisons among attributes featuring strong influence with respect to those pointed out by IIMH. The new matching percentages in Fig. 4(B) correspond to the following results: 17.72% at the advanced level, 22.26% at the basic level and 59.63% at the intermediate level. As can be seen, there were little variations around the levels of potentials obtained that, despite not significant, may become relevant in cases where there is a higher dispersal among the assessments performed for the different categories (clusters) concomitantly with the existence of a marked influence relation.

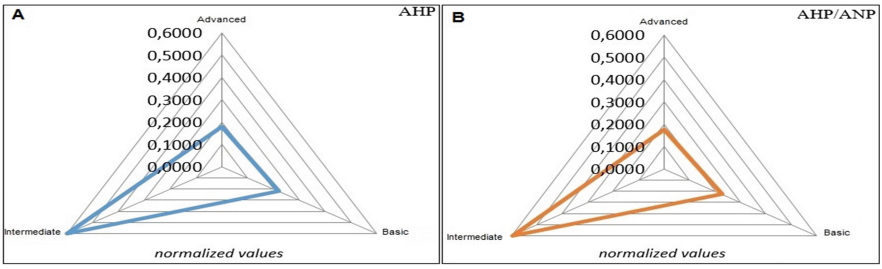

Fig. 4. Interoperability potential assessed through AHP/ANP.

The sensitivity analysis enables checking the variation in the final level of the interoperability potential using the variation in the weighting of one of the perspectives or attributes taken into account. In order to check this variation, the information obtained through IIMH can be used as support in identifying attributes with higher organizational

relevance. Such as for example, analysis of the attribute "Patient Centric" under the perspective of "Process Management", in Fig. 5, shows a variation in its weighting pointing to an expressive influence in displacing the percentage of the potential level of the hospital entity towards the "advanced" level and a reduction in the "intermediate" and "basic" levels. This attribute becomes, therefore, candidate to efforts in organizational enhancement reducing, in this way, the barriers to interoperability in the process dimension.

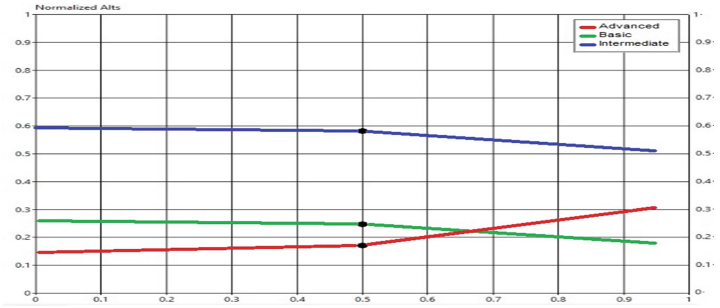

Fig. 5. Sensitivity analysis of the AHP method.

Supported on the subnetwork modeling resource afforded by Super Decisions, the diagnostic assessment obtained through the analysis of the different levels in capability from the perspectives of interoperability can be understood. In this way, the priority view inherent to each assessment matrix and its priority vector for an aggregate weighting at the level/cluster considered is achieved. Fig. 6 presents the results obtained that, according to the global level of the interoperability potential of the hospital, positions the better part of the perspectives in the intermediate level. A special standout is given to the perspectives of "Process Management" and "Human Resources" featuring the lowest weighting and trending towards the basic level. There is a consensual understanding in this diagnostic by the specialists of the entity under assessment in perceiving the human element and process coordination as barriers to a better organizational performance.

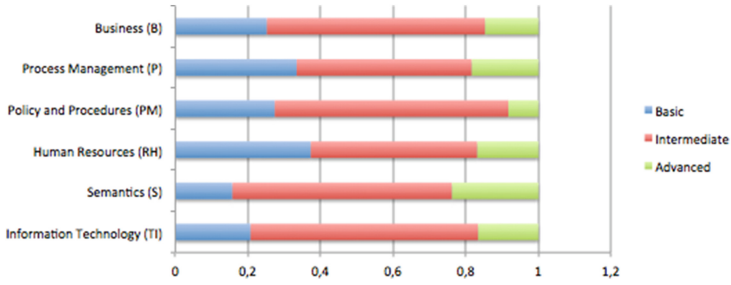

Fig. 6. Capability levels.

5 Conclusion

Hospitals have faced a demand higher than their capacity to provide services, evidencing the rising need to improve communication, cooperation, interaction and processes within the entity. The organizational performance of the hospital finds in the interoperability perspectives an important assessment tool, driving conclusions on the points for improvement and performing again an assessment for the calculation of this progress. In this way, a diagnostic assessment of the attribute capability levels, as well as of the level of interoperability for the hospital in relation to the processes delivered in the sector of oncology has an applicable and measurable value. Based on the development framework, the stages of obtaining and organizing knowledge in order to drive the concept for the assessment model based on the AHP/ANP methods were characterized. In its development cycle, the proposal facilitates the design of the MCDM/A methods, compliant with the requirements and attributes in assessing interoperability in healthcare, including inaccurate, qualitative and tacit knowledge items. The assessment, however, enabled diagnosing the existing level of interoperability in the oncology sector as compared to the remainder of the hospital, using the stages of collection and interviews, existing in-house policies and information systems as inputs for the assessment. After the execution of the AHP and ANP models, the oncology sector was identified as largely positioned in the intermediate level. The sensitivity and capability analysis of the attributes and perspectives of interoperability, promoted by these MCDM/A structures, permit a diagnostic analysis very rich in the defining of priorities of organizational endeavors in minimizing or eliminating barriers to a better performance. Human Resources (RH) and Process Management (P) are subject to organizational actions in order to improve their capability levels on the basis of the related attributes, leading the hospital to a higher maturity level. In future work, the deployment of other MCDM/A methods in new cases and entities in the healthcare domain will be studied. Methods that stand out to this end are Electre-Tri and Promethee in integration with the Process Mining techniques in an effort to conciliate qualitative and tacit information to quantitative information stemming from the observation of historical data and information systems targeted at the hospital administration/management.

References

1. Chen, D., Doumeingts, G., Vernadat, F.: Architectures for enterprise integration and interoperability: past, present and future. Comput. Ind. **59**(7), 647–659 (2008)
2. Cestari, J.M.A.P., Loures, E.R., Santos, E.A.P.: Interoperability assessment approaches for enterprise and public administration. In: Demey, Y.T., Panetto, H. (eds.) OTM 2013. LNCS, vol. 8186, pp. 78–85. Springer, Heidelberg (2013). doi:10.1007/978-3-642-41033-8_13
3. Rezaei, R., Chiew, T.K., Lee, S.P., Aliee, Z.S.: Interoperability evaluation models: a systematic review. Comput. Ind. **65**(1), 1–23 (2014)
4. National E-Health Transition Authority: NEHTA 2.0: Interoperability Framework, Australia (2007)
5. European Commission: Directorate-General for Communications Networks, Content and Technology. eHealth European Interoperability Framework (2013). ISBN: 9789279303890

6. Campos, C., Chalmeta, R., Grangel, R., Poler, R.: Maturity model for interoperability potential measurement. Inf. Syst. Manage. **30**(3), 218–234 (2013)
7. Chen, D., Vallespir, B., Daclin, N.: An approach for enterprise interoperability measurement. In: MoDISE-EUS, pp. 1–12 (2008)
8. Guedria, W., Lamine, E., Pingaud, H.: Health systems interoperability: analysis and comparison. In: 10ème Conférence Francophone de Modélisation, Optimisation et Simulation, MOSIM 2014 (2014)
9. Chen, D., Daclin, N.: Framework for enterprise interoperability. In: Interoperability for Enterprise Software and Applications, I-ESA05, pp. 77–88 (2005)
10. Praveen, T., Devlin, N., Marsh, K.: Multiple criteria decision analysis for health care decision-making - an introduction: report 1 of the ISPOR MCDA emerging good practices task force. Value Health **19**, 1–13 (2016). Elsevier Inc. On behalf of International Society for Pharmacoeconomics and Outcomes Research (ISPOR)
11. Marsh, K., et al.: Assessing the value of healthcare interventions using multi-criteria decision analysis: a review of the literature. Pharmacoeconomics **32**(4), 345–365 (2014)
12. Kahraman, C.: Fuzzy Multicriteria Decision Making - Theory and Applications with Recent Developments. Springer, New York (2008)
13. Saaty, T.L.: Decision making with the analytic hierarchy process. Int. J. Serv. Sci. **1**(1), 83–98 (2008)
14. Marca, D., McGowan, C.: IDEF0 - SADT Business Process and Enterprise Modeling. Ecletic Solutions Corporation (1993). ISBN:0963875000
15. Salmon, K.: Oncology Networks: Best Practices – A Study of Governance, Resources and Clinical Coordination (2011). http://www.kurtsalmon.com/uploads/HC-Oncology-120203VFSP1.pdf. Accessed 12 Apr 2016
16. Scuissiatto, V., Loures, E., Portela, E.: Interoperability assessment approach in cancer healthcare. In: TE 2016 Scientific Programme, 4 October 2016
17. Jain, N.J., Singh, A.R.: AHP And QFD Methodology For Supplier Selection (2014). doi: 10.7763/IPEDR
18. Detro, S.P., Morozov, D., Lezoche, M., Panetto, H., Santos, E. P., Zdravkovic, M.: Enhancing semantic interoperability in healthcare using semantic process mining. In: 6th International Conference on Information Society and Technology (ICIST 2016), February 2016