Evaluation of Health Data Warehousing:
Development of a Framework and Assessment of Current Practices

by

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A Dissertation Submitted in Partial Fulfillment
Of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

In the School of Health Information Science

Supervisory Committee

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Abstract

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If knowledge has been gathered by the practitioners' community in the area of health data warehousing evaluation, it is mostly relying on anecdotal evidence instead of academic research. Isolated dimensions have received more attention and benefit from definitions and performance measures. However, very few cases can be found in the literature which describe how the assessment of the technology can be made, and these cases do not provide insight on how to systematize such assessment.

The research in this dissertation is aimed at bridging this knowledge gap by developing an evaluation framework, and conducting an empirical study to further investigate the state of health data warehousing evaluation and the use of the technology to improve healthcare efficiency, as well as to compare these findings with the proposed framework.

The empirical study involved an exploratory approach and used a qualitative method, i.e. audio-taped semi-structured interviews. The interviews were conducted in collaboration with the Healthcare Data Warehousing Association and involved 21 participants who were members of the Association working in a

mid- to upper-level management capacity on the development and implementation of health data warehousing. All audio-taped interviews were transcribed and transcripts were coded using a qualitative analysis software package (NVivo, QSR International). Results were obtained in three areas. First, the study established that current health data warehousing systems are typically not formally evaluated. Systematic assessments relying on predetermined indicators and commonly accepted evaluation methods are very seldom performed and Critical Success Factors are not used as a reference to guide the system's evaluation. This finding appears to explain why a literature review on the topic returns so few publications. Second, from patient throughput to productivity tracking and cost optimization, the study provided evidence of the contribution of data warehousing to the improvement of healthcare systems' efficiency. Multiple examples were given by participants to illustrate the ways in which the technology contributed to streamlining the care process and increase healthcare efficiency in their respective organizations. Third, the study compared the proposed framework with current practices. Because formal evaluations were seldom performed, the empirical study offered limited feedback on the framework's structure and rather informed its content and the assessment factors initially defined.

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List of Abbreviations

CSF	Critical Success Factor
ETL	Extract Transform Load
GIS	Geographic Information Systems
HDWA	Healthcare Data Warehousing Association
MeSH	Medical Subject Heading
MPP	Massively Parallel Processing
OLAP	On-Line Analytical Processing
ROI	Return on Investment
SQL	Structured Query Language
SWOT Analysis	Strengths, Weaknesses, Opportunities, and Threats analysis
TAM	Technology Acceptance Model
TEAM	Total Evaluation and Acceptance Methodology

Acknowledgements

The guidance and assistance provided by my Supervisor, Dr. Andre Kushniruk, were instrumental in accomplishing the research. His knowledge of health information systems' evaluation was very beneficial. Equally important was the input of my Committee Members, Dr. Noreen Frisch and Dr. Alex Kuo. They both added a complementary perspective to my work, the former from a medical, clinical and nursing standpoint, and the latter from a technical point of view. The financial support provided by the University of Victoria's School of Health Information Science and the Government of British Columbia greatly facilitated the conduct of the empirical study.

The existence of the research itself was initially supported by Dr. Dennis Protti who recommended that I pursue a doctorate degree, endorsed my topic of interest, and introduced me to someone he presented as "the best mentor I could ever hope for." The opportunity to benefit from Dale Sanders' knowledge and experience were indeed an unsurpassable experience. His intellectual and personal qualities were invaluable. His relentless attention and immediate availability throughout this venture made a tremendous difference. More importantly, Dale Sanders introduced me to the Healthcare Data Warehousing Association, the organization which enabled the conduct of the empirical study under the best possible conditions. Over the past three years, through my participation at the organization's annual conference, I was also given the opportunity to present and discuss my work with those involved in health data warehousing on a daily basis. The research would have never come to fruition without the time and effort contributed by Lee Pierce, Suzan McFarland and those who participated in the empirical study.

The proficiency and dedication of Faye Wolse were instrumental in achieving optimum use of the data analysis software, while the expertise, talent and communications skills of my editor, Mayne Ellis, enabled me to produce materials of high editorial quality.

Lastly, reaching the finish line in a timely fashion would have never been possible without the support of my co-workers at Rebalance^{MD} who never questioned and systematically accommodated the time requirements of this project.

"You might ask: "Why evaluate?" For years, health IT has been implemented with the goals of improving clinical care processes, health care quality, and patient safety. In short, it's been viewed as the right thing to do. In those early days, evaluation took a back seat to project work. Frequently, evaluations were not performed at all – at a tremendous loss to the health IT field. Health IT projects require large investments, and stakeholders increasingly are demanding to know both the actual and future value of these projects. As a result, we as a field are moving away from talking about theoretical value, to a place where we measure real value. We have reached a point where isolated studies and anecdotal evidence are not enough – not for our stakeholders, nor for the health care community at large. Evaluations must be viewed as an integral piece of every project, not as an afterthought."

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CHAPTER I – RESEARCH CONTEXT AND MACRO-LEVEL ENVIRONMENT

Regardless of funding mechanisms, the percentage of the gross national product devoted to healthcare has risen to unprecedented levels over the past decade. The reasons most commonly cited range from a rise in the prevalence of treated conditions to an increase in the volume and intensity of services as well as the aging population. A cause far less investigated is the inefficiency of healthcare systems. It is acknowledged that 50,000 to 100,000 lives are lost each year in the US as a result of medical error (Bodenheimer, 2005; Bush, 2007; Orszag, 2008). Also indicative of inefficiencies are the wide variations in practices, outcomes and costs that can be found across providers, geographical regions and patients (Bodenheimer, 2005; Bush, 2007; Orszag, 2008). In 2008, the US Congressional Budget Office estimated that an average US$700 billion, an equivalent of 5% of the GDP, was spent each year on care that is not shown to improve health outcomes (Bodenheimer, 2005; Bush, 2007; Orszag, 2008). When higher than average expenses occur, it appears that the extra share of spending is actually wasteful as it does not correspond to any improvement in health status. Waste is considered a measure of inefficiency and can be found throughout the healthcare system from the overuse of procedures not proven useful and the underuse of treatments known to be effective to quality defects resulting in tests being redone or even in detrimental health effects (Bentley, Effros, Palar, & Keller, 2008).

Addressing healthcare inefficiencies and waste requires something that is not yet readily available. Measures are still pieced together from various sources. They do not cover extensively how much is being spent and where, and they do not systematically assess the clinical conditions and practices that drive expenditures growth (Fodeman & Book, 2010). The ability to link data on spending, medical care, conditions and other key indicators in a timely fashion and on a large scale is still missing as well. (Fodeman & Book, 2010).

The absence of reliable measures in turn leads to a lack of frameworks to properly categorize inefficiencies and determine strategies to address them. It also impacts the use of management philosophies which have been successful in other sectors of the economy, e.g. Continuous Process

Improvement. In contrast, healthcare outcomes often remain linked to individuals and isolated causes such as physician negligence and technical issues rather than processes themselves (Laffel & Blumenthal, 1989). Ultimately, it results in the persistence of funding mechanisms based on volume rather than the efficient provision of care (Bentley et al., 2008; Fodemand & Book, 2010).

1. Health Data Warehousing

Measures and the ability to link data are part of a broader context: information, i.e. the accumulation of transactional data into a meaningful context. When properly structured and made available to targeted users in a timely fashion, information becomes knowledge (Bose, 2003). This next level of understanding originates in the collection of evidence, which is in essence the purpose of data warehousing and the prerequisite for improving processes (Sanders & Protti, 2008). Not only can information technology facilitate the collection of health data, but with the use of health data warehouses, it can also facilitate the query and broad analysis of such data. By making large amounts of clinical, financial and operational data available in customized and useable formats, health data warehouses help uncovering critical utilization patterns, they facilitate the integration of demographic and consumer data collected by transactional systems, and they help shortening the turnaround time to provide the data needed for analyses. New knowledge can then be generated, opportunities for improvement can be unveiled and the efficiency of healthcare systems can be increased (Goldstein, 2000).

1.1. Health Data Warehousing Definition

A data warehouse is a "centrally managed and easily accessible copy of data collected in the transaction information systems of a corporation. These data are aggregated, organized, catalogued and structured to facilitate population-based queries, research and analysis" (Sanders & Protti, 2008).

Best known as the "father of data warehousing," Bill Inmon characterizes the data warehouse as "a subject-oriented, integrated, non-volatile and time-variant collection of data in support of management's decisions." (Bush, 2007) The data is not organized to support specific applications such as laboratory or imaging systems, but rather by subjects, i.e. patients, and is therefore subject-oriented. The data originates in multiple operational systems, and is integrated both by definition and content. The purpose

of a data warehouse is to extract data from operational systems and transform it into formats suitable for data analysis. As opposed to operational systems in which data is deleted when it is no longer needed by a particular application, data warehouses retain data over time. It is the non-volatility of the data that makes historical analysis possible. As opposed to operational systems which store the most recent version of the data, data warehouses keep track of it, including a history of the changes that took place. Time-variance enables trends analysis over time. Finally, the purpose of the data is to improve management by gaining a better understanding of the enterprise (Inmon, 2005).

Several attributes characterize a data warehouse. A data warehouse is large by definition, i.e. it contains up to thousands of terabytes of data or more. The system offers a historical perspective, i.e. it can cover up to 30 years or more. The technology integrates data from several transaction information systems, i.e. data is collected from source systems such as billing, registration or scheduling. The analysis provided by a data warehouse spans across multiple business processes, e.g. the data pertaining to a billing system will be compared against the data contained in a scheduling system. A data warehouse provides an explorative approach. It offers insight into areas that have not yet been investigated and issues that have not yet been anticipated. The output of the data warehouse takes the form of reports and metrics. From the collection of the data to its transformation for query purposes and the production of reports, data warehouses require the intervention of specialized staff (Sanders & Protti, 2008).

The key role of a data warehouse is to provide decision-makers with the compelling business intelligence that enables them to understand problems, discover opportunities, and measure performance. To effectively play this role, the data warehouse must integrate the internal and external data acquired over time and translate it into current conditions. In doing so, the data warehouse is the instrument that enables decision makers to locate and apply relevant data, and helps them to predict and measure the impact of their decisions over time (March & Hevner, 2007; Pedersen & Jensen, 1998).

1.2. Health Data Warehousing Process

In order to become a real organizational asset leveraged throughout the organization, data must be properly identified and inventoried. It must be extracted, organized, combined, stored and managed in a secured manner. Based on user requirements and reporting expectations, a master data model is established as the foundation for the warehousing effort which, as shown on Figure 1, encompasses four functions.

Data Acquisition. A data warehouse acquires its data from the organization's operational systems as well as from systems external to the organization such as suppliers and regulatory institutions. Not only must the data be extracted from the source systems, but it must be cleaned and transformed to conform to the standardized architecture, and it must be loaded into the data warehouse. Known as extract-transform-load or ETL, this function is at the core of data warehousing. Equally central is the establishment of robust metadata, i.e. the comprehensive documentation of the data and all processes related to the data warehouse including data models, a data dictionary and ETL load statistics which must be made readily available to the user community (Adelman, 2003; Imhoff, Galemmo, & Geiger, 2003; Inmon, Imhoff, & Terdeman, 1999; Sakaguchi & Frolick, 1997).

Data Warehouse Population. In order to be presented to users in a uniform and consistent manner, the data that flows in the data warehouse must follow a consistent and logical process. Based on the organization's requirements and experience, the storage of the data usually follows the dimensional approach, which stores data in a form similar to both its true dimensionality and the form needed at the time of reporting, or the relational approach, which relies on relational database management principles (Inmon et al., 1999; Sakaguchi & Frolick, 1997).

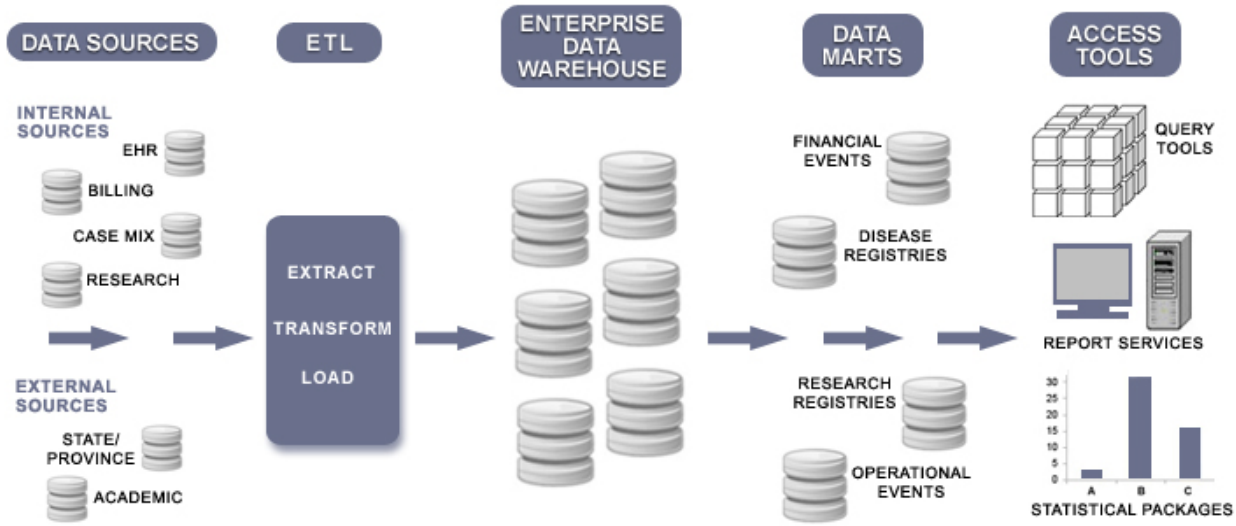

Figure 1 – Health Data Warehouse Architecture

Data Marts Creation. To better address the needs of specific users, smaller subsets of data are drawn from the data warehouse in the form of custom-designed databases and offer a multidimensional view of the data such as by service or location as well as over time. Such subsets enable a better understanding and greater probing of the data, and offer faster responses to queries (Hristovski, Rogac, & Markota, 2000).

Information Access. In order to meet the information needs of the end-users, a series of analysis and reporting tools must be made available that leverage the latest technology with minimal overlap. Structured Query Language (SQL) queries are used on an ad-hoc basis and involve specific interfaces. On-Line Analytical Processing (OLAP) is used to "slice and dice" large volumes of data, and provides analysts with an interface to manipulate views and levels of aggregation. Web reporting enables the selection and presentation of customized reports from web interfaces. Dashboards and scorecards utilize graphical interfaces to present key indicators and quality measures and allow drilling down into top-level measures to assess their components. Data mining techniques apply algorithms to summarize, model and cluster data with the aim of identifying novel and potentially useful correlations and patterns in data. Statistical analysis can be applied to the data, e.g. measures of central tendency, analysis of variance, regression, and time series analysis. Geographic Information Systems (GIS) provide geographic displays of data and can be used, among others, to analyze where resources are needed for specific products and

services, or to demonstrate geographic variations in distribution or consumption patterns (Akhtar, Dunn & Smith, 2005).

2. State of Health Data Warehousing Evaluation

If the anticipated benefits of data warehouses are quite significant, the system requires ample financial and technical resources, as well as qualified labor and time. By spanning across entire organizations, it is subject to multiple individual and organizational factors. Its dependency on existing source systems renders the quality of its output vulnerable, and since its output is in the form of reports and metrics used for decision support purposes, numerous and potentially critical repercussions are associated to its use. The level of complexity is further increased when data warehousing is applied to healthcare. Medical data is more voluminous and heterogeneous than the data found in any other economic sector, and in order to cover all aspects of the care process, data warehouses must address areas as varied as clinical research, treatment effectiveness, financial analysis and customer relationship.

If the literature extols the virtues of health data warehouses, there is little evidence of their assessment. As indicated in Chapter II, even when extended to sectors not related to healthcare, the review of the current literature returns very few publications on data warehousing evaluation. Only isolated dimensions such as data and system quality or user satisfaction have received more attention and benefit from definitions and performance measures (Curtis & Joshi, 1998; Wixom & Watson, 2001). Whenever knowledge has been gathered by the practitioners' community, it is mostly relying on anecdotal evidence. Furthermore, very few cases can be found that describe how the assessment of the technology can be made, and these cases do not provide insight on how to systematize such assessment.

In lieu of evaluation principles and methods, the concept of success often serves as a basis to the system's assessment. As discussed in Chapter V, Critical Success Factors (CSFs) are an application of such concept. CSFs are elements identified as vital in order for an organization or project to achieve its mission and reach successful targets. Failure to meet the objectives associated with CSFs results in the failure of the project or organization (Watson, Gerard, Gonzalez, Haywood, & Fenton, 1999). The research departed from CSFs. Not only does this practice reduce assessments to a dichotomous

approach, but it relies on ill-defined and contentious concepts. Data warehouses can be successful if implemented within budget, but at the same time their effective use may not. The converse can equally be true, or the technology may be highly appreciated by users but nonetheless not widely used. In other words, some CSFs are identified without being empirically used and some of the factors used involve different measuring mechanisms. The notion of success has also been the object of extensive academic research. For over twenty years, DeLone and McLean have attempted to define information systems success along with the dimensions of success themselves. Their theoretical model was chosen as a foundation to the research described in this dissertation. The latter also departed from the DeLone and McLean theory. If its model and the empirical studies conducted to apply it have helped establish a set of success factors and measures, a consensus is still lacking as to what the concept of success entails. In the absence of such consensus, the use of factors such as the actor for whom success is defined and rather his/her view can prevail within an organization persists. As a result, the assessment of information systems remains often unaddressed, and the comparison of systems across organizations remains largely impossible (Berg, 2001; Forsythe & Buchanan, 1991).

3. Research Objectives

Rather than attempting to determine success, the research in this dissertation focused on evaluation. A literature review was conducted on the evaluation of health data warehousing, on applicable information systems theories and on evaluation research. The review results are presented in Chapter II. An evaluation framework was developed and is presented in Chapter III. An empirical study was conducted to further investigate the state of health data warehousing evaluation and the use of the system to improve healthcare efficiency. The empirical study design is presented in Chapter IV and the findings are described in Chapter V. Lastly, the findings were compared with the proposed framework. Current evaluation practices and the comparison are discussed in Chapter V and VI.

The empirical study addressed the following three questions:

Research Question #1: What is the state of health data warehousing evaluation?

Data warehouses are known to be effective enablers of evidence-based decision making. Up until the current dissertation research, whether or not the technology was formally evaluated remained largely unknown. It was therefore of paramount importance to address the following questions:

1.1. Do healthcare organizations formally evaluate their data warehouse?

1.2. Is health data warehousing evaluation perceived as necessary?

1.3. When conducted, how are the assessments performed and what do they entail?

1.4. Do the assessments rely on Critical Success Factors?

Research Question #2: How is data warehousing used to improve healthcare efficiency?

Health data warehouses can be used to facilitate financial and performance analyses as well as to assess effectiveness, productivity and resources utilization. They can also be used for medical, clinical and nursing purposes, among others through the analysis of treatment patterns and protocols. It is also stated that the technology can be of benefit to research and population health. The use of data warehousing is also particularly relevant when organizations want to perform outcomes assessments with the aim of improving healthcare delivery and containing costs. At a time when such objectives had become a priority, it was essential to investigate whether the technology delivers on the promises. The following questions were designed to this effect:

2.1. How is health data warehousing used to address inefficiencies and waste?

2.2. How is health data warehousing used to improve processes and reduce costs?

2.3. How is data warehousing used to address medical, clinical, nursing and research purposes?

Research Question #3: How should the evaluation of health data warehousing be conducted?

Along with qualified labor and time, health data warehousing requires ample financial resources. It relies on the existence of a broad network of applications. It also depends on organizational structures and motivations. The technology thus involves considerable risk from development to long-term use, and therefore justifies proper evaluation. In order to address the content and ways in which the latter should be performed, the following questions were explored:

3.1. Which evaluation dimensions and factors should be considered?

3.2. Which evaluation methods should be used?

Insight into these areas was provided in the study described in this dissertation through an exploratory approach that used a qualitative method (i.e. semi-structured interviews) to collect data from mid- and upper-level management experts working on the development and implementation of health data warehousing. Chapter IV describes the design of the study. Chapter V presents the findings in four separate sections. Section 1 describes the sample characteristics. Section 2 addresses the first research question on the sate of health data warehousing evaluation and the second research question on the use of the technology to improve healthcare efficiencies. Section 3 addresses the third research question on how the evaluation of health data warehousing should be conducted. Section 4 presents findings which enabled the researcher to go above and beyond the objectives set forth by the research proposal and added an explanatory value to the research.

By addressing the above questions, the research bridged a key knowledge gap and contributed to the advancement of health information systems and evaluation research. The latter are characterized by a fragmented approach and usually limit assessments to single dimensions. Through its holistic and inclusive approach, the research aimed at demonstrating how the integration of a plurality of dimensions can be achieved.

Plurality of users. Most evaluations focus on specific users and tend to ignore the fact that different users will react differently to the same application, starting with how they define their information needs and how they go about to answer them (Lee & Garvin, 2003; Kreps, 2002). Paradoxically, even though health information systems are introduced to improve patient care, their evaluation seldom addresses the impact on care itself (Kreps, 2002). Health data warehousing is designed to support decision making in all areas of healthcare, from clinical to financial, operational and research, and therefore serves a broad range of users with varied background and areas of expertise. The objective of health data warehousing precisely is the improvement of healthcare processes and delivery, and thus ultimately the improvement

of care itself. As shown by the utilization dimension of the proposed framework, the assessment of the technology offers the opportunity to take a plurality of users into account while addressing the direct impact on the care provided.

Plurality of systems. Evaluations are usually limited in scope and focus on single systems. This in turn limits the generalization and transferability of the findings (Ash, 2000). Since data warehousing is made up of and depends on various applications, its evaluation is by definition multi-system. As indicated by the framework's technical dimension, this not only concerns the varying source systems from which data warehouses draw but also the various applications used to treat the data and make it available to end users.

Plurality of phases. Assessments tend to be considered in a dichotomous way. Formative or ex-ante evaluations are performed before the system design is finalized and aim at incorporating user feedback into the design itself. Summative or ex-post evaluations are conducted after systems have been implemented and focus on outcome and impact with the aim of influencing future developments. If an inclusive view is to be gained from the evaluation, the latter should take the form of an ongoing process that calls for different methods (Sjoberg & Timpka, 1998). From design to implementation, data warehousing projects require a considerable amount of time and the use of the technology serves a long-term perspective. Consequently, the evaluation of data warehouses cannot be circumscribed to a single point in time but must be considered within a broader timeframe and needs to take the entire System Development Life Cycle into account. The proposed framework aims at demonstrating how to gain such an inclusive perspective by using assessment factors retrospectively and to analyze current conditions.

Plurality of findings. While the literature mainly refers to best practices and critical success factors, whenever researchers study the flip-side of the stories, they find, among others, troublesome unintended consequences and failure rates which in some cases can be as high as 50% (Smith, 2002). Beyond publication bias, there is an obvious and understandable reluctance on the part of organizations to be presented as embodying failure. Stakeholders on the other hand, are first and foremost concerned with

project promotion, regardless of the findings of the evaluation process. Not only is the lack of transparency and objectivity ethically questionable, but it prevents from understanding the causes of negative outcomes, and most importantly it prevents from improving upon unsatisfactory results (Friedman & Gustafson, 1977). Although far from fully reported, the pattern seems to equally apply to health data warehousing. The research aimed at demonstrating the predominance of sound and objective evaluation over the determination of success.

Plurality of methods. Despite their advantages, quantitative evaluation methods such as experimental designs and randomized controlled trials (Mair & Whitten, 2000) have come under criticism as they do not provide insight into the causes of the findings. Neither do they enable the investigation of processes or the concurrent study of multiple organizational dimensions. If such methods may be considered by some as a research standard (Kaplan & Shaw, 2004), the understanding of factors such as roles, norms and values cannot be reduced to quantitative measures. More importantly, because of the multiple dimensions of health information systems, evaluation requires the simultaneous use of various methodologies (Kaplan, Kvasny, Sawyer & Trauth, 2002). The proposed framework aims at demonstrating the need to combine different methodologies. Equally important is the integration of the invaluable work, knowledge and experience generated outside of research environments, which are neither reported nor disseminated through conventional channels. The research aimed at following such pluralistic approach, at opening doors to the generation and testing of new theories, and at communicating transferable knowledge.

The next chapter presents the results of the literature review on health data warehousing evaluation, and the review of applicable information systems and evaluation theories.

CHAPTER II - LITERATURE REVIEW

A review of the literature was performed on health data warehousing evaluation and was extended to the assessment of the technology in economic sectors other than healthcare. The following sub-sections present the results of both reviews.

1. Health Data Warehousing Evaluation

1.1. Search Strategy

The term “evaluation” is a Medical Subject Heading (MeSH) and a general subject heading referenced by the US Library of Congress, but the terms “health data warehouse” and “health data warehousing” are not. Therefore, only general keywords could be used to perform a literature review on the topic of health data warehousing evaluation. The following search string was constructed: “health data warehous*” AND (evaluation OR assessment OR inspection OR audit OR critique OR usefulness OR effectiveness). Alternate search strings were used with the terms “clinical data warehous*” and “medical data warehous*” but returned nearly identical results.

Results were limited to studies published between January 1990 and March 2014; conducted in North America, Europe, Australia and New Zealand; and published in English.

The literature survey returned the following numbers of articles:

ACM Digital Library: 120

Business Source Complete: 10

CBCA FullText Reference: 23

CINAHL: 20

Google Scholar: 17,400

Health Technology Assessment: 183

PubMed: 110

Telemedicine Information Exchange: 5

Web of Science: 48

The first step of the review consisted in removing duplicate studies based on the title and abstract of the articles. The second step consisted in reviewing the top 2,500 articles according to the following relevance criteria: address one or more evaluation dimension and/or factor; pertain to the purpose of and/or need for evaluating the technology, its usefulness and/or effectiveness; and refer to established evaluation methods of health information systems.

1.2. Review Results

Among the articles reviewed, only two addressed the evaluation of health data warehousing based on the above-mentioned criteria:

Schubart, J. R., & Einbinder, J. S. (2000). Evaluation of a data warehouse in an academic health sciences center. *International Journal of Medical Informatics*, *60*(3), 319-333.

Einbinder, J. S., Scully, K. W., Pates, R. D., Schubart, J. R., & Reynolds, R. E. (2001). Case study: a data warehouse for an academic medical center. *Journal of Healthcare Information Management*, *15*(2), 165-176.

All other articles referred to the use of the technology in specific settings or in specific research environments rather than to its evaluation. The two articles returned describe assessments that consist in determining whether users' needs are met. These assessments provide feedback on the value of the data warehouse and on needs for improvement which can then be planned for accordingly. They can also be used for internal marketing purposes, and to justify funding for the technology. These articles recommend three methods to assess health data warehousing: usage statistics, user surveys and system tracking.

Usage Statistics. Monitoring the user population and usage patterns enables management to assess the success of a health data warehouse. The measures will apply to aspects such as the number of

individuals having authorized access to the technology, the number of logins, and the number of queries submitted. Tracking those indicators over time provides a usage profile of the data warehouse. Nevertheless, unlike technologies such as electronic medical records which are used several times a day, data warehouses tend to be used sporadically. Hence the measurement of the frequency of use alone is not sufficient to properly assess the technology, and must be supplemented by qualitative analyses (Einbinder et al., 2001; Schubart & Einbinder, 2000).

User Surveys. To further evaluate the adoption and effectiveness of a health data warehouse, a more in-depth analysis must be conducted, and users must be surveyed with respect to the types of queries submitted, the ease of use of the system, the format in which results are provided, the accuracy of the underlying data, and the response time of the system. Questionnaires are developed to cover the above-mentioned factors, and are given to users who have authorized access to the data warehouse. Beyond functionality, it is also necessary to assess the strengths and weaknesses of the technology, and aspects such as institutional oversight, management and implementation issues as well as the accuracy with which the data warehouse meets initial needs. Answers to those questions can be provided by interviewing CIOs, medical directors or administrators, and the professionals involved in the conceptualization, development and funding of the technology. Even though difficult, surveying potential users, i.e. staff members who are aware of the existence of the data warehouse and wish to use it, is also essential. Even more difficult but equally important is the interview of secondary users, i.e. those who benefit from the technology but do not query the warehouse themselves. Additionally, particular attention should be paid to dissociating real users who are seeking answers to their queries from those who access the technology out of curiosity or use it for reasons other than its intended purpose. With regard to content, the evaluation should investigate whether the health data warehouse provides access to sources other than internal systems. Aspects such as technical components and usability should also be evaluated for the execution of complex queries. The assessment of users' tolerance level to the formulation of complex queries and the learning of new technologies is also necessary to determine the needs for additional training and technical support. Ultimately, the evaluation should provide feedback on

the value added by the system, i.e. which queries were addressed by the data warehouse that would not have been answered had it not been in existence (Einbinder et al., 2001; Schubart & Einbinder, 2000).

System Tracking. The periodic review of the queries submitted to the data warehouse can add to the above-mentioned qualitative analyses. By auditing usage logs, users can be identified and their interview can help better understand the types of queries that were submitted and how they were answered (Einbinder et al., 2001; Schubart & Einbinder, 2000).

The article by Einbinder and colleagues (2001) as well as the articles by Shubart and Einbinder (2000) show the limitations of users' surveys when conducted to assess data quality. Since the data is aggregated and integrated from multiple sources, its direct comparison against user experience is nearly impossible. Users access the data through analysis and reporting tools, but they are not directly exposed to it. Determining the accuracy of results and evaluating how queries are handled should therefore not be mistaken with assessing the quality of the data that originates in the source systems. To this effect, the developers in charge of the legacy systems should monitor data accuracy, among others through automated data auditing, while the health data warehouse evaluation should provide additional tests such as comparing reports with existing hospital records (Einbinder et al., 2001; Schubart & Einbinder, 2000).

The evaluation should also confirm whether the health data warehouse fully supports all levels of data analysis. At the patient level, it should be possible to view and analyze data pertaining to individual patients, for example to find a pattern in the development of a disease and to determine the best possible treatment. At the group level, users should be able to analyze treatments and outcomes for groups of patients and compare them to standards in order to improve the care process. This level is usually research-oriented and is more useful from a scientific standpoint. At the enterprise level, the opportunity should be given to combine all data (clinical, financial, and demographic) to investigate healthcare utilization. This level addresses overall performance and is important from a managerial standpoint (Einbinder et al., 2001; Schubart & Einbinder, 2000).

2. Data Warehousing Evaluation

2.1. Search Strategy

Considering the small number of articles returned from the above-mentioned review of articles pertaining to the evaluation of health data warehouses, the literature review was extended to the evaluation of data warehousing in sectors not related to healthcare. The databases used for the review were dedicated to business, computer science and engineering topics. The search string was adjusted accordingly: "data warehous*" AND (evaluation OR assessment OR inspection OR audit OR critique OR usefulness OR effectiveness). Results were limited to studies published between January 1990 and March 2014; conducted in North America, Europe, Australia and New Zealand; and published in English. The following numbers of articles were returned:

ACM Digital Library: 800

Applied Science and Technology Index: 5

Compendex: 454

Computer Science Index: 62

Computing Reviews Online: 95

IEEEXplore: 229

ScienceDirect: 1,813

Web of Science: 173

Business Source Complete: 80

Google Scholar: 17,300

PubMed: 142

2.2. Review Results

The method used for the health data warehousing evaluation review was applied to that of data warehousing evaluation. Among the articles reviewed, only 5 met the review criteria:

Golfarelli, M., & Rizzi, S. (2009). *A comprehensive approach to data warehouse testing*. Proceedings of the ACM 12th International Workshop on Data Warehousing and OLAP (DOLAP'09), Hong Kong, China.

Ku, C. S., & Zhou, Y. H. (2004). *Qualitative evaluation profiles of data-warehousing systems architecture*. Proceedings of the ISCA 19th International Conference on Computers and their Applications, Seattle, WA.

Oates, J. (1998). Evaluating data warehouse toolkits. *Software*, IEEE, *15*(1), 52–54.

Park, Y. T. (2006). An empirical investigation of the effects of data warehousing on decision performance. *Information & Management*, *43*(1), 51–61.

Wells, D., & Moore, A. (1999). How to do a data warehouse assessment (and why). *Journal of Data Warehousing*, *3*(2), 22–35.

Once again, most articles referred to the use of the technology in specific settings or for research purposes. Similarly, they referred to isolated aspects such as data quality or information system investments rather than the evaluation of the technology. The publications pertaining to data warehousing evaluation referred to enterprise data warehouses and offered a comprehensive view of the topic. They provided valuable information about the evaluation framework and process, the assessment of the impact of the technology on decision performance and about data warehousing testing.

2.2.1. Data Warehousing Evaluation Framework

Regardless of the information system at stake, maintaining neutrality and objectivity can be challenging when evaluating information systems. The purpose of the data warehouse assessment should be clearly articulated around the provision of an objective identification of roles, responsibilities, quality metrics, organizational and methodological gaps, and should aim at contributing the best possible solutions to the progress and long-term viability of the warehousing effort under review. Similarly, there should be a clear consensus on the scope, methods, deliverables and expected outcomes of the assessment (Oates, 1998; Wells & Moore, 1999).

Another challenging element is the complexity of the data warehouse itself, including its many technical and organizational components. In order to address this multifaceted environment, the evaluation should provide an analysis of the gaps, risks, constraints and opportunities for five key dimensions: business

needs, information architecture, technical architecture, methodology and project management, as well as organizational factors (Oates, 1998; Wells & Moore, 1999).

Business Needs. The purpose of the evaluation is to determine the extent of the needs assessment initially performed, to examine its content, identify its gaps and study the impact the latter have had on the warehousing project. The evaluation needs to examine how business requirements were captured, organized and prioritized, and whether the data warehouse implementation and deliverables were aligned with those requirements (Oates, 1998; Wells & Moore, 1999).

Information Architecture. This part of the evaluation focuses on logical data structures and assesses their feasibility, completeness and documentation. Additionally, it analyzes the methods and assumptions applied to data sourcing and transformation as well as their validation and mapping to the business requirements. The completeness, user requirements and management approaches to metadata are also part of the evaluation of the information architecture (Oates, 1998; Wells & Moore, 1999).

Technical Architecture. From a technical standpoint, the evaluation must examine the hardware and software components, along with the network infrastructure and physical database design to identify potential risks and constraints and their impact on the performance, maintenance and scalability of the data warehouse. The effectiveness and usability of ETL, modeling and querying tools should be assessed, and reference should be made to the metadata assessment performed earlier (Oates, 1998; Wells & Moore, 1999).

Organizational Evaluation. A key factor that needs to be addressed when evaluating a data warehouse is organizational readiness, i.e. the capability of the business and information technology entities to assume responsibility for ongoing technical and business support, as well as the management and enhancement of the hardware, software and front-end applications. While the organizational assessment focuses on roles and responsibilities, the evaluation of project planning and methodology addresses the

translation of organizational commitments into specific resources, tasks and processes (Oates, 1998; Wells & Moore, 1999).

Project Planning and Methodology. At the project level, the evaluation must review variables such as time, resources and results, as well as decision making, communication and issue resolution processes. The data warehousing life cycle is examined along with the project team composition and skills and the overall release and implementation strategy (Oates, 1998; Wells & Moore, 1999).

2.2.2. Data Warehousing Evaluation Process

The authors (Oates, 1998; Wells & Moore, 1999) recommend that data be collected for each of the above-mentioned dimensions. Structured interviews validated by group sessions with primary stakeholders help prioritizing findings with regard to business needs. Extensive document review and identification of potential issues are applied to the remaining perspectives. The findings are then compared against benchmarks and best practices, and key issues are identified for each area under review (Oates, 1998; Wells & Moore, 1999).

The next step consists of gap analysis and in mapping the business needs against architectural and organizational problems to understand which issues impact the business the most and must be addressed first. Based on the mapping, problem affinity analysis is performed to identify potential solutions which are then compiled and integrated into an action plan (Oates, 1998; Wells & Moore, 1999).

2.2.3. Evaluation of the Impact of Data Warehousing on Decision Performance

The goal of data warehousing is to facilitate decision making, i.e. to improve its quality by providing relevant and timely information to lower its inherent level of uncertainty. Research has been conducted to compare traditional databases with partial data warehouses and enterprise-wide data warehouses through a laboratory experiment simulating a marketing environment where sales force deployment had to be decided based on trend analyses (Park, 2006). The result of this study by Park (2006) indicated that fully capable data warehouses significantly improved decision performance while partial data

warehouses did not. Moreover, the study showed that compared with traditional databases, partial data warehousing did not bring any significant improvement. Since it is one of the few studies to examine the effects of data warehousing on decision performance, the contribution of the research is of great value. However, the experiment was made with surrogate managers, i.e. MBA students. It involved a small volume of data and was restricted to a few specific tasks. Consequently, the findings cannot be generalized outside the marketing field neither can they be extended to professional decision makers or to tasks that require the analysis of larger volumes of transactional data (Park, 2006).

2.2.4. Data Warehouse Testing

Even though conducted for different purposes, software testing and the evaluation of information systems share methodological approaches. As part of the development life cycle, testing aims at providing an objective view of an application and an understanding of the risks associated with its implementation. Techniques are therefore used to detect errors and defects while executing the application.

Unlike software testing which applies mainly to program code, data warehouse testing has a broader scope. It addresses the validity of the data itself as well as the correctness and usefulness of the information provided to users. Because of the ongoing nature of data warehousing projects, testing is not circumscribed to the steps prior to deployment, but extends beyond system release. Testing must apply to the conceptual and logical schemas and to the data repositories, and needs to focus on the ETL process (back-end testing) and on reporting and analysis technologies (front-end testing). The former compares the consistency of the data loaded in the data warehouse with the source data, while the latter verifies the correctness and aggregation of the data made available through reporting systems. Some of the techniques applied include functional tests to verify compliance with business requirements; usability tests to assess ease of use and comprehensibility; performance tests to ensure that the technology performs properly under average workload; stress tests to determine the performance level under extreme workload; recovery tests to assess responses to crashes and hardware failures; security tests to verify data protection levels; and regression tests to ensure proper functioning after changes have taken place (Golfarelli & Rizzi, 2009; Ku Ku & Zhou, 2004).

As attested by the above-mentioned results, the treatment by the literature of data warehousing evaluation is rather sparse. If this is particularly true with regard to healthcare, it also applies to other economic sectors.

The review of the literature on data warehousing evaluation was supplemented by an investigation of applicable information systems and evaluation theories. The etymology of the word "theory" is the Greek term "theoria" (θεωρία) which designates the rational, abstract and generalized explanation of the nature of the world. In modern use, theories encompass concepts, models and schemes which not only have an explanatory but a predicting value. Besides the provision of a body of knowledge, theories also provide a basis for action. Moreover, because of their explanatory nature, they address the notion of causality (Gregor, 2002; Schwandt, 1994).

3. DeLone and McLean Theory of Information System Success

The DeLone and McLean theory of information systems success (D&M IS Success Model) offers the most suitable theoretical background to the research. It is considered the dominant model for measuring IS success and it is one of the few comprehensive assessment models available to date. The authors' objective has been to define success (the model's dependent variable) in order to predict IS success by identifying and testing operative independent variables. To do so, the authors advocate comprehensiveness, i.e. the association of multiple measures from the model's interdependent dimensions into a comprehensive instrument. Since its publication, the D&M IS Success Model has been used by many researchers and is a theory for which empirical studies have been systematically tracked (AMCIS, 2008).

3.1. Initial DeLone and McLean Information System Success Model

When initially published in 1992, the theory posited six dimensions of IS success (system quality, information quality, use, user satisfaction, individual impact and organizational impact) and incorporated them into an overall model in which several interdependencies were established. The D&M IS Success Model is not only a process but a causal model. It aims at revealing causal relationships between

dimensions. Just as use and user satisfaction are affected by the quality of the system and the quality of the information, use itself is affected by user satisfaction and vice versa. Similarly, individual impact depends on use and user satisfaction and will in turn affect organizational impact (IEEE, 2002).

When DeLone and McLean first published the model, they emphasized several considerations with regard to its use and empirical testing. Because of the lack of consensus on success measures, they acknowledged that the choice of variables is determined by a wide series of factors from the type of system at stake and the organizational context to research methods and the level of analysis. They recommended consolidating such variables. They highlighted the need for further investigation of the impact of organizational performance. They not only emphasized that the construct should be considered as multidimensional, but that its measurement should be multidimensional as well and should involve weighted average of the selected criteria (IEEE, 2002).

3.2. Model Update

In 2003, DeLone and McLean published an updated version of their initial model. Two new dimensions (service quality and intention of use) were added, and the impact dimensions were merged into a single "net benefits" concept. The total number of dimensions remains unchanged at six. The model leaves the determination of causality to specific empirical studies. The recommendations initially made by the authors remain unchanged as well. However, they added three suggestions: referring to validated measures whenever possible, referring to actual measures instead of self-reported ones and referring to measures which go beyond the frequency of use to encompass aspects such as the nature, quality and appropriateness of use (AMCIS, 2008; Delone & McLean, 2003; IEEE, 2002).

In the current model, quality encompasses three dimensions (information quality, systems and service quality) which DeLone and McLean recommend measuring separately since they can affect use and user satisfaction individually or together. Use has been relabeled "intention to use" to emphasize attitude rather than behavior, and to facilitate the interpretation of aspects such as mandatory/voluntary, informed/uninformed or effective/ineffective use. With the concept of "net benefits," the means to

dissociate positive from negative impacts while using a single variable regardless of the level of analysis has been added to the model (AMCIS, 2008; DeLone & McLean, 2003; IEEE, 2002).

3.3. Model Testing and Validation

Several studies have helped validate the D&M IS Success Model. In seven studies, the association between system use and individual impact was found to be significant (AMCIS, 2008; DeLone & McLean, 2003; Goodhue & Thompson, 1995; Guimaraes & Igbaria, 1997; IEEE, 2002; Igbaria & Tan, 1997; Teng & Calhoun, 1996). Five studies showed that the association between system quality and user satisfaction as well as individual impact is statistically significant (Etezadi-Amoli & Farhoomand, 1996; Goodhue & Thompson, 1995; Seddon & Kiew, 1994; Teo & Wong, 1998; Wixom & Watson, 2001). In four studies, the association between information quality and user satisfaction as well as system use and individual impact was proven to be statistically significant (D'Ambra & Rice, 2001; Etezadi-Amoli & Farhoomand, 1996; Liu & Arnett, 2000; Molla & Licker, 2001; Palmer, 2002; Rai, Lang, & Welker, 2002; Seddon & Kiew, 1994; Teo & Choo, 2001; Weill & Vitale, 1999; Wixom & Watson, 2001). One study showed a significant correlation between user satisfaction and individual impact (Seddon & Kiew, 1994).

Multiple studies have also identified different measures and applied different instruments: organizational benefits of information systems (Mirani & Lederer, 1998); business value, user orientation, internal process and future readiness dimensions of information systems (Martinsons, Davison, & Tse, 1999); extended user satisfaction (Teo & Choo, 2001) and information satisfaction instrument (Li, 1997); multiple investigations of system use (Igbaria, Zinatelli, Cragg, & Cavaye, 1997; Larsen & Wetherbe, 1999; Straub, Limayem, & Karahanna-Evaristo, 1995; Taylor & Todd, 1995; Teng & Calhoun, 1996); systems usage measurement based on the nature and purpose of the system (Doll & Torkzadeh, 1998); and measurement of initial system usage vs. intentions of future use (Agarwal & Prasad, 1997).

If the above-mentioned studies helped gather a considerable body of knowledge, they also demonstrated the need for a continuing effort to refine the model through further testing and challenging.

A series of information systems constructs provide theoretical background for the assessment of individual factors such as user satisfaction or information quality. Davis' Technology Acceptance Model (TAM) introduced the notions of perceived usefulness and perceived ease-of-use as determinants of information systems acceptance and use (Davis, 1989). Shannon and Weaver proposed three levels of information systems output measurement: technical level (information systems accuracy and efficiency), semantic level (transfer of information's meaning), effectiveness level (information's impact on the user) (Shannon & Weaver, 1949). Ajzen's Theory of Planned Behavior, a psychological predictive construct, has been applied to information systems to factor attitudes and behaviors in the assessment of use (Ajzen, 1991).

The aim of the research in this dissertation being the development of an inclusive framework, the approach is one of a broad and all-inclusive assessment instead of the investigation of a narrow evaluation factor. Therefore, the choice was made to retain the D&M IS Success Model as the theoretical foundation for the research.

4. Health Information Systems Evaluation Research

Evaluation research is grounded in an array of theories from quantitative and objectivist to qualitative and subjectivist as well as positivist and interactionist. Deductive and inductive approaches, theories of change and resistance and other social science references have been applied with varied degrees of success. The research methods are equally varied and include randomized controlled trials, experimental designs, simulations, usability testing, cognitive studies, record and playback techniques, network analysis, ethnography, economic and organizational impacts, action research, surveys, qualitative methods and interpretive analyses, technology assessment, benchmarking, as well as SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis, ROI (Return on Investment) and cost-benefit analyses (Anderson & Aydin, 2005; Kaplan & Shaw, 2004; Ramamurthy, Sen, & Sinha, 2008).

Studies have been conducted on the evaluation of health information systems for over four decades. Their focus ranges from management issues, user acceptance and the diffusion and adoption of

technologies, to lessons learned and critical success factors. The dimensions investigated cover technical and financial factors, workflow issues, institutional and organizational aspects, communication patterns, cognitive processes, user characteristics and preferences, usability issues and information content and presentation (Anderson & Aydin, 2005; Kaplan & Shaw, 2004; Ramamurthy et al., 2008).

Even though they share similar logic and procedures, empirical studies aim at building scientific knowledge while evaluation research has an immediate and tangible purpose. Beyond satisfying rigorous scientific conditions, evaluation research aims at providing evidence for immediate decision making. This confers de facto a political dimension to evaluation, i.e. the assessment of stakeholders' needs, values and interests (Leys, 2003). Moreover, evaluation is increasingly called upon within regulatory and policy environments as a basis for projects adoption or discontinuation (Lehoux & Blume, 2000). As a result, evaluation can be seen as a source of potential disruption. More importantly, some may try to limit its scope, purpose and methods, or reject its conduct and findings all together (Kaplan & Shaw, 2004).

To address this pitfall and avoid fragmented approaches, researchers have attempted to provide evaluation frameworks and standardized models. Among these are TEAM (Total Evaluation and Acceptance Methodology) which relies on role, time and structure as a basis for standardization (Grant, Plante, & Leblanc, 2002); Kaplan's 4Cs framework which uses communication, control, care and context as multi-dimensional guidelines (Kaplan, 1997); and Shaw's socio-political framework which is based on actors, resource flows, knowledge production and power relations (Shaw, 2002). Attempts have also been made at matching specific evaluation methods with specific research questions, and have focused on the evaluation process itself (Gremy & Degoulet, 1993).

Nevertheless, to this day there is no consensus among researchers as to the usefulness of such frameworks or even the need for a unified evaluation model (Brender & McNair, 2000; Gremy & Degoulet, 1993). As a result, a multitude of approaches and methods continue to be applied and few studies address the impact of health information systems in a comprehensive fashion. The reason invoked is that a fragmented view is preferable to a simplified version of reality that might omit key factors while favoring

others (Kaplan & Shaw, 2004). A more recent current, multidisciplinary teams, offers a more conciliatory path. By joining forces, social and computer scientists, health informatics specialists as well as experts in organizational behavior and economics, make it possible to produce more robust and extensive assessments (Fulop, Allen, Clarke, & Black, 2003).

The next sections review traditional and contemporary approaches to health information systems along with the study designs and actors involved, and the obstacles to evaluation research.

4.1. Need for Evaluation

Over the past decades, health information systems have increased in number and sophistication. They are now used in more complex environments to address more complex tasks. Moreover, they are integrated within and between organizations, making them interdependent and relying on vast networks of varied technologies. (Moehr, 2002; Smithson & Hirschheim, 1998).

In this context, assessing effectiveness to determine which products are most useful and how they can be best utilized has become essential. Providing accountability, supporting further development and contributing to knowledge discovery has equally become indispensable. In healthcare, evaluation has an additional purpose: the enhancement of healthcare delivery and health promotion. Additionally, as system failures and cases of systems that do not accomplish their intended purposes are increasingly being reported, not only must cost effectiveness be justified, outcomes must be assessed as well (Anderson & Aydin, 2005; Kreps, 2002).

4.2. Traditional Approaches to Evaluation

Traditional evaluation approaches were acquired from varied disciplines and carried many of their characteristics. The software quality approach originates in total quality management and the manufacturing sector (McDaniel, 2002). The financial approach originates in cost-benefit analysis used in economics and accounting (Smithson & Hirschheim, 1998). The user satisfaction approach originates in job satisfaction study as recommended by managerial best practices (Smithson & Hirschheim, 1998).

Traditional approaches to evaluation were also developed according to underlying hypotheses, from objective assumptions based on engineering to subjective assumptions based on social science. Along the continuum, three key dimensions were usually covered. Efficiency addressed issues of performance and quality in reference to specifications and benchmarks. It involved extensive testing procedures and called for techniques such as simulation. The latter consisted in developing models, i.e. abstractions of real systems, which were used to assess the impact of variations in inputs as well as changes in structure and operational conditions. Variations could thus be simulated without disrupting work settings while providing estimates of the real systems (Smithson & Hirschheim, 1998). Effectiveness focused on how systems impact businesses with issues such as utilization and investment, and called for user satisfaction studies, cost-benefit and risk analyses (Smithson & Hirschheim, 1998). Understanding aimed at studying organizational contexts, and referred to social sciences and psychology (Smithson & Hirschheim, 1998).

The methods initially used to assess health information systems followed the experimental or clinical trials research model. Because they aimed at measuring impact according to the variance theory, i.e. by explaining changes in variables as a result of implementing a system, traditional approaches focused on a limited number of criteria and seldom lead to outcome improvements. If they illustrated how systems made a difference, they did not address why the impacts were obtained (Heathfield, Pitty, & Hanka, 1998; Kaplan, 1997).

4.3. Current Approaches to Evaluation

In an effort to explain the impact of information systems, researchers have since studied the processes that contribute to the observed outcomes, among others are issues of communication (impact on the way departments interact), care (impact on care delivery), control (impact on organizational control), and context (relationship between the impact and the setting where the technology is introduced) – which Kaplan calls the 4Cs of evaluation (Kaplan, 1997, 2001).

The primary objective of today's assessments is to improve systems by either providing feedback on issues that have been unveiled or by leveraging opportunities that have been revealed. To do so,

evaluation goes beyond costs and benefits quantification to analyze the value and risks of investments, including their contribution to both business strategy and organizational effectiveness. This broader analysis encompasses four concepts.

History. At any given time in the development life cycle, information systems present constraints and opportunities inherited from previous developments. The knowledge and understanding of such historical background is factored in by current approaches.

Infrastructure. The organization's infrastructure and its capability to leverage resources are also part of today's assessments.

Informal procedures and information flows. Not only are these factors intrinsic to the work accomplished with the systems, they are a direct result of social relationships. Identifying them along with the roles and patterns that result from them has become an integral part of evaluation.

Stakeholders. Be it individuals, groups or larger collectivities, each stakeholder has perspectives, interests and opinions that affect the ways in which information systems are developed and implemented. Understanding such perspectives is now considered a part of the evaluation process (Symons, 1991).

Current approaches are characterized by comprehensive frameworks which focus on technical, economic, and organizational aspects; use multiple methods and collect a variety of data to maximize the understanding of causal relationships and strengthen results; are flexible enough to incorporate issues as they arise and knowledge as it becomes available; are longitudinal to capture changes over time; and are both formative and summative (Kaplan, 1997).

Current approaches are also oriented toward end-users. Ergonomic assessments are used to assess users' workload when operating an information system (e.g. number of keystrokes, the information memorized to perform an operation). Cognitive and usability assessments are used to study the

compatibility of the system with the cognitive processes involved when users accomplish specific tasks (e.g. the mental process involved when a physician diagnoses a patient). They focus on the quality of the human-computer interaction with aspects such as understandability. Functionality assessments are used to evaluate how well a system fits within an organization with regard to work processes (Brender, 1998; Clarke et al, 1994; Nykänen, Chowdhury, & Wigertz, 1991; Preece, 1990).

The contemporary approach to evaluation is thus comprehensive in nature. It assesses the system's worth and quality. It not only addresses issues of validity, but also of utility and usefulness. It demonstrates whether the system meets its intended requirements and goals. On-time and within budget delivery of an information system that correctly and efficiently performs specified requirements will not be fully satisfactory if the use of the system is hindered by poor understandability or because it is hard to modify or integrate with other applications (Brender, 1998; Clarke et al., 1994; Liebowitz, 1986; Nykänen et al., 1991; Preece, 1990; Southon, 1999).

4.4. Questions Addressed by and Study Designs of Evaluation

In practical terms, evaluation seeks to answer questions such as which system should be selected and installed, what is the usability of the system, is the system used as intended, does the system work effectively, does the system impact the quality of care, is the system cost-effective (Moehr, 2002; Protti, 2002; Wyatt & Wyatt, 2003).

To address these questions, evaluation relies on objectivist and/or subjectivist designs. Objectivist designs are based on metrics that enable statistical analysis while subjectivist designs focus on documenting differences through qualitative data collected in natural settings to develop concepts that assist in understanding users' views and experiences (Forsythe & Buchanan, 1991).

The measurements collected through the evaluation process are obtained through quantitative and/or qualitative methods. Quantitative methods must be both reliable (i.e. obtain the same result regardless of who applies them) and valid (i.e. effectively measure what was intended) to gather data such as patient

waiting times, number of ordered tests or number of patients seen per hour. Quantitative methods essentially rely on surveys and system-generated metrics. Qualitative methods include observations, interviews, focus groups or case studies and aim at identifying motivations and documenting the impact of the system by taking organizational dimensions into account (Protti, 2002; Wyatt & Wyatt, 2003).

The most common assessments are quality assurance or technical reviews, compliance audits, budget performance reviews, personnel productivity reviews, computer performance evaluations, service level monitoring, user attitude surveys, post-installation reviews, cost-benefit analyses, cognitive analyses, time-motion and work sampling reviews, and social network analyses.

4.5. Actors Involved in Evaluation

Four categories of professionals are involved in health information systems assessments. Developers are usually responsible for system testing, performance evaluation as well as the description of the skill level needed from users. Project managers are often in charge of assessing the development process from a resource and consumption perspective. Users and domain experts are usually involved prior to the design phase to help determine operational characteristics, and should be able to provide feedback after implementation to confirm the adequacy of the system and/or highlight its unintended consequences. Third parties may be called to improve the objectivity of the assessments and should therefore not be directly involved in the development of the system. Information technology department quality assurance groups, autonomous internal audits and external experts usually play such roles (Clarke et al., 1994; Nykänen et al., 1991).

4.6. Obstacles to Evaluation Research

Because of the complexity of today's technology, disentangling individual systems can be rather difficult and evaluating them separately from the product or service they enable is no longer appropriate. Additionally, since information systems are part of a larger infrastructure that serves cooperative work, their evaluation needs to go beyond a mere technical and economic approach to include organizational dimensions (Moehr, 2002; Smithson & Hirschheim, 1998).

Health information systems evaluation goes far beyond the assessment of a product and requires an understanding of the behavioral components that affect and are impacted by the system. Design and implementation involve lengthy processes, and once the technology has been introduced, its use extends over long periods of time. Each stage requires different methods, and at each stage various changes may occur that affect results. Since healthcare environments cannot be frozen in time, the assessment itself must be flexible enough to take such changes into account (Ammenwerth, Gräber, Herrmann, Bürkle, & König, 2003; Anderson & Aydin, 2005; Fitzgerald, 1998; Heathfield et al., 1999; Stead, 1996).

Healthcare environments involve various professional groups, external influences and, more importantly, patients. Assessment projects can thus be hindered by the necessity to collect potentially conflicting viewpoints. Different study designs and/or methods may be needed which can in turn increase the amount of resources necessary. Failure to address this issue may result in evaluations of limited value or even in a misrepresentation of the environment (Ammenwerth et al., 2003; Anderson & Aydin, 2005; Fitzgerald, 1998; Heathfield et al., 1999).

From funding to the number of participants, each aspect of the evaluation depends on stakeholders support. Fear of negative outcome or of results that are too difficult to act upon may hinder the undertaking of the evaluation project (Ammenwerth et al., 2003; Anderson & Aydin, 2005; Fitzgerald, 1998; Heathfield et al., 1999).

The evaluation of health information technologies is further complicated by the evolving nature of both technology and healthcare environments. Newer technologies such as telemedicine and the visualization used for genetic alterations illustrate the need for equally evolving evaluation methods that encompass ethical questions and issues such as the dehumanization of healthcare technologies (Mort, May, & Williams, 2003). As healthcare distances itself from the traditional clinical encounter in favor of a virtual and Internet-based provision of services, the focus of evaluation has to shift from individual to integrated systems and networked technologies. Another recurrent challenge for the evaluation of health

information systems is the need for assessment methods to cover the lifetime and stages of technologies, from development to stabilization and routine use (Kaplan & Brennan, 2001).

Kaplan and Shaw best summarize the above-mentioned issues when stating: “Thus evaluation needs to address more than how well a system works. Evaluation also needs to address how well a system works with particular users in a particular setting, and further, why it works that way there, and what “works” itself means. Evaluation needs to address how conceptions of whether a system works change with time and with who is making the judgment. This scope to evaluation will help answer such key questions as:

- Why are the outcomes that are studied as they are?
- What might be done to affect outcomes?
- What influences whether information and communication technologies will have the desired effects and desired by whom?
- What from one study might be generalizable or transferable to other sites or applications?
- How can information and communications technologies be used so as to improve patient care?” (Kaplan & Shaw, 2004, p. 220)

Based on the review of the above-mentioned theories, an evaluation framework was developed for health data warehousing. The following chapter describes the framework and discusses further the concepts of information systems’ evaluation and success.

CHAPTER III - PROPOSED EVALUATION FRAMEWORK

The first section of this chapter addresses the ways in which the proposed framework built on and departed from the DeLone and McLean theory of information systems success, and incorporated evaluation principles. The next sections highlight health data warehousing specificities and introduce the health data warehousing evaluation framework.

1. Evaluation vs. Information Systems Success

Practitioners and businesses are eager to measure and predict information systems success because they involve considerable investments, because the productivity return is not guaranteed and because a fair amount of system failures occur (AMCIS, 2008).

Researchers have investigated the issue for many years as well. As indicated in chapter IV, the DeLone and McLean theory of information system success aims at defining a dependent variable designated by the term “success.” Delone and McLean associate “success” and “effectiveness.” However, according to the Oxford Dictionary, the definition of these two terms is different.

The etymology of success is the Latin substantive *successus* and the Latin verb *succedere* which means "to come close after" (*sub*: close to; *cedere*: go). In contemporary English, success means "favorable outcome" and "accomplishment of an aim or purpose." Synonyms include accomplishment, achievement, attainment, fruition, gain, realization and win. Antonyms include failure and loss (OED, 2012).

Effectiveness is defined as “the degree to which something is successful in producing a desired result.” In contrast to efficiency, effectiveness is determined without reference to costs. Synonyms include capability, effect, efficacy, performance, success, use and validity. Antonyms include ineffectiveness, unproductiveness and uselessness (OED, 2012).

Not only do the terms differ, but the latter can be seen as conditioning the former. Moreover, effectiveness does not encompass financial considerations. However, DeLone and McLean include measures such as ROI and cost-benefit analysis in their model. As well, the Delone and McLean model puts little to no emphasis on the System Development Life Cycle and rather assumes that the information system is in use, i.e. in the post-implementation phase. In evaluation terms, this would equal to performing summative assessments only. There are many stages prior to post-implementation over the course of which determining success might be desired or necessary. This would correspond to formative assessments. In the case of health data warehouses, because of the constantly evolving nature of the system, it is essential to provide both a retrospective and current account of the system, which equals to performing both formative and summative evaluations.

Not only is success an ill-defined term but it is often presented as having one and only one alternative: failure. This makes information systems assessments highly contentious and reduces them to a dichotomous approach that ignores the multitude of stages that exist between the two extremes of an actually lengthy continuum. As a result, the determining factor is often the actor for whom success is defined, and rather his/her view can prevail within the organization rather than well-established criteria. This in turn makes it impossible to compare systems across organizations, and it is equally impossible to determine whether an organization may actually have tried to accomplish too much or too little. Information systems can be successful if implemented within budget, but at the same time their effective use may not. The converse can equally be true, or systems may be highly appreciated by users but not widely used. Moreover, what makes a specific information system successful (for example, reducing errors in reports) may not apply to another (for example, shortening the time to data delivery). Even though DeLone and McLean's work has contributed a great deal to reducing the risk of referring to criteria that are not empirically used, uncertainty remains as to the reproducibility of their model across information systems (Adelman, 2003; Berg, 2001; DeLone & McLean, 1992; Forsythe & Buchanan, 1991).

In the absence of a clear definition of success, enterprises also resort to the use of CSFs and address what makes information systems successful rather than success itself. CSFs are elements identified as vital in order for an organization or project to achieve its mission and reach successful targets. Failure to meet the objectives associated with these factors results in the failure of the project or organization (Moyer, 2003; Watson & Haley, 1998; Watson et al., 1999). The notion of guaranteeing success by merely replicating a series of factors is rather debatable. Moreover, CSFs do not provide any understanding of the causes for success or failure, nor do they offer insight into how systems can be improved (Berg, 2001; DeLone & McLean, 1992; Forsythe & Buchanan, 1991).

In light of the above, rather than determining success, the research in this dissertation has focused on evaluation. If success is defined as accomplishing an aim or achieving objectives, the research posited that assessments should not only focus on objectives themselves but on the extent to which and how such objectives are achieved. A common question in this regard is: did the technology achieve its intended results? The answer to this question is very seldom "yes" or "not at all," but rather a set of various arguments ranging between these two opposites. Hence it is believed that what is paramount in order for organizations to utilize information systems in an effective and efficient manner is the understanding of the arguments at stake and of the reasons why they are what they are. In order to address such arguments with regard to health data warehousing, the research in this dissertation involved the construction of an evaluation framework the aim of which is to provide in-depth feedback on and analysis of the technology.

2. Health Data Warehousing Specificities

One of the major challenges in evaluating health data warehouses is the need to address the multidimensional aspects of the technology. Since the system encompasses multiple applications, its evaluation cannot be assessed by single measures and requires a broader framework. However, as indicated by DeLone and McLean (1992, 2002, 2003), the proliferation of measures is equally harmful, and the dimensions of health data warehouses must be consolidated within this overall framework. The

latter must be representative of the environments in which the technology is put to use, it must have an explanatory value, and indicate in a logical fashion the interaction among its components (Guida & Mauri, 1993; Moore, 1998).

Furthermore, several factors make the need for an evaluation framework particularly relevant. The technology requires ample financial resources, as well as qualified labor and time. The system involves a complex mix of hardware and software. By spanning across entire organizations, it is subject to multiple individual and organizational factors. Its dependency on existing source systems renders the quality of its output vulnerable. Its output being in the form of reports and metrics used for decision support purposes, numerous and potentially critical organizational repercussions are associated to its planning, design, implementation and utilization. Its use in healthcare encompasses additional factors related to medical, clinical, nursing and research utilization.

3. Proposed Framework

Even though DeLone and McLean (1992, 2002, 2003) indicate that the application of their model is dependent on the organizational context, they do not identify the organizational dimension as an independent variable the way they do with other components such as system quality or net benefits. In this regard, the proposed framework departs from that of DeLone and McLean by making the organizational dimension an intrinsic part of the evaluation framework.

The proposed framework also departs from that of DeLone and McLean as it does not aim at determining success but rather at offering a framework for the conduct of an inclusive evaluation of health data warehousing.

As shown on Figure 2, three broad dimensions have been chosen to construct the proposed framework. The organizational dimension is the broader context in which the technology exists and encompasses the key business determinants of its development and use. The technical dimension is defined as the architectural and technological choices made to address the business requirements as well as the

optimum treatment of the data necessary to the provision and use of analytics and reports. The utilization dimension pertains to the use of the system in healthcare settings for financial, operational, medical, clinical, nursing and research purposes.

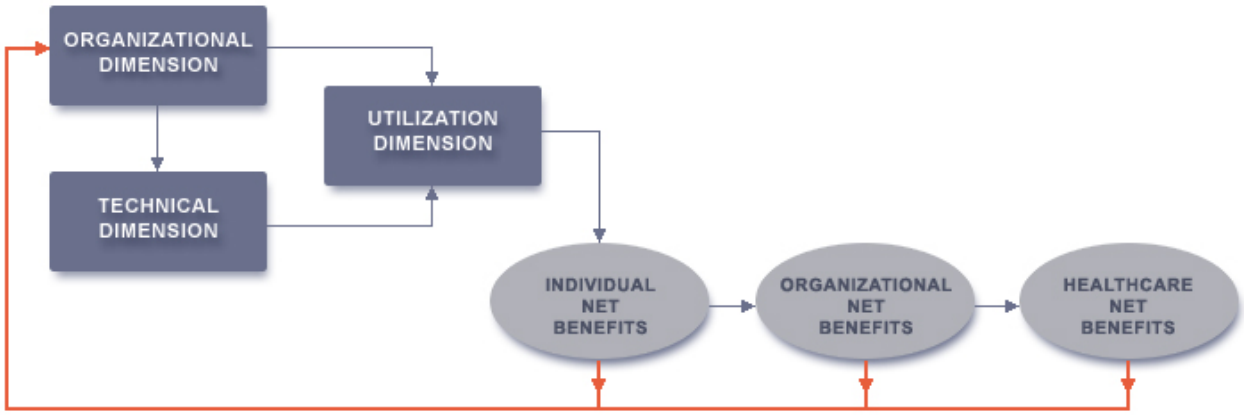

Figure 2 – Proposed Health Data Warehousing Evaluation Framework

The positive impact, or net benefits of the technology, is also considered at three different levels: individual (i.e. healthcare professionals), organizational (i.e. healthcare organizations) and healthcare as a whole (i.e. the healthcare systems). As in the DeLone and McLean model (1992, 2002, 2003), net benefits designate the system's positive outcome. However, the proposed framework differs from that of DeLone and McLean in that it specifies the entities to which the benefits are attributed. DeLone and McLean's model (1992, 2002, 2003) is intended for researchers and the authors leaves the decision of the analysis level to those performing the studies. In contrast, the proposed framework is not exclusively intended for researchers to assess the success of health data warehousing. The proposed framework is also intended for use by professionals in healthcare settings and thus must be tailored as closely as possible to the system and its use in healthcare environments.

Several relationships are considered between dimensions: the organizational dimension determines both the technical and utilization dimensions, while utilization is also directly determined by the technical dimension. This three-dimensional complex then produces net benefits which have their own relationships. Impact at the organizational level is dependent on that gained on an individual basis and

leads to net benefits on a larger scale, i.e. at the healthcare system level. The framework also accounts for a feedback loop from the impact levels to the organizational dimension.

To enable the application of the framework, its dimensions and net benefits must be broken down into components and factors against which the health data warehouse is evaluated. Figure 3 shows this additional layer and the following sections describe the components and their individual factors.

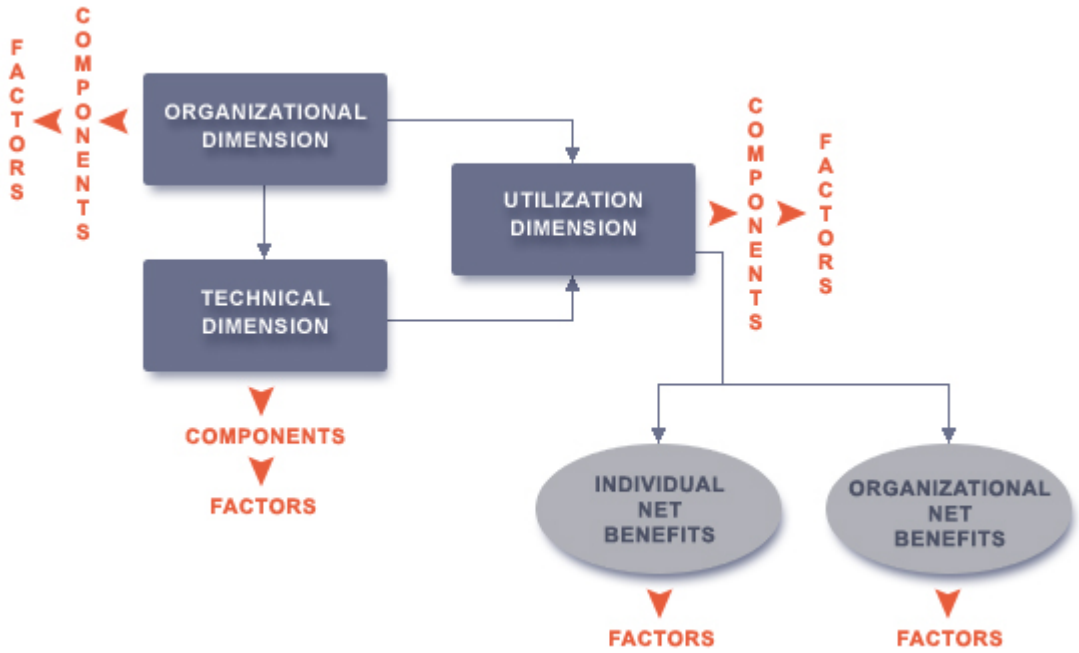

Figure 3 – Framework's Components and Factors

4. Evaluation Framework's Dimensions, Components and Net Benefits

5.1. Dimension #1: Organizational Dimension

As stated in the previous chapter, the organizational dimension of health data warehousing encompasses the broader context in which the technology exists and the key business determinants of the development and use of the technology. In order to effectively evaluate the health data warehouse, the research recommended that the dimension be broken down into five components.

Component #1A: Legitimate business needs. A data warehouse represents a considerable investment, and the delivery of data does not automatically enable its use. Organizations must ensure

that business areas and data owners contribute to the warehouse effort, and that data is used to its best benefits. Moreover, they must be open to opportunities and committed to the changes called for by process improvement in order for data warehousing to produce its intended results (ACM, 1998; Vatanasombut & Gray, 1999).

Component #1B: Management support. Management support is considered one of the key determinants that helps overcome political resistance, encourages participation and conditions user behavior and acceptance. It is strengthened by the existence of a champion who supports and promotes the project and provides information, material resources, and political support (DeWitt & Hampton, 2005; Rist, 1997; Watson & Haley, 1998; Watson et al., 1999).

Component #1C: Resources. Beyond offering the ability to acquire the necessary equipments, sufficient resources are key to execute tasks and meet project deadlines. The availability of sufficient resources also increases the chance to overcome organizational issues and provides the means to better communicate organizational commitments (Watson & Haley, 1998; Watson et al., 1999).

Component #1D: User needs assessment. Identifying users' needs is critical to assess how access to information can be best implemented to achieve business goals. On the other hand, by involving users in the data warehouse project, opportunity is given to them to better understand the technology's potential which makes them more likely to adopt the system (Ives, Olson, & Baroudi, 1983; Moyer, 2003).

Component #1E: User support. End-users have various backgrounds and their experience with databases varies as well. Not only should the data warehouse be useful to novice as well as advanced users, but training and support programs should be established so that its use can be maximized (Ives et al., 1983).

4.2 Dimension #2: Technical dimension

Chapter I defined the technological dimension of health data warehousing as comprising the architectural and technological choices made to address the business requirements as well as the optimum treatment of the data necessary to the provision and use of analytics and reports. To enable the evaluation of the system, this dimension must be broken down into four components.

Component #2A: Data. Data quality has a direct impact on the analytics and reports produced as a result of querying the health data warehouse. Since the latter makes data available by integrating an organization's source systems, the quality of such systems is equally paramount. From often incompatible medical standards to coding schemes, healthcare data presents unique challenges and requires careful translation. Moreover, it originates in multiple internal and external sources and must be provided in various formats.

Component #2B: Architectural choices. Appropriate architectural choices must be made in accordance with the organization's requirements and its need to cover administrative and financial functions as well as medical and research purposes. The choices apply to a range of technical aspects from data standards to metadata and system scalability.

Component #2C: Technological choices. Hardware, software, methods and programs must be available and of the best possible quality. Such tools are numerous and sophisticated, and their availability impacts the implementation and use of the health data warehouse.

Component #2D: Performance. High performance and high availability are closely associated. Not only must the data be up-to-date, but it must be continuously made available to guarantee a reliable and constant flow of information within the organization.

4.3. Dimension #3: Utilization dimension

As stated in Chapter I, the use of the system in healthcare settings serves financial, operational, medical, clinical, nursing, and research purposes. This dimension includes three components which must be assessed in order to provide a comprehensive evaluation of the system.

Component #3A: Financial and operational utilization. Be it for day-to-day operations or system-wide strategies, health data warehousing provides the analytics necessary to optimize processes, resource utilization and operating costs. The assessment should therefore address the use of the technology at the financial and operational level.

Component #3B: Medical/clinical/nursing utilization. By enabling the comparison and contrast of the causes, symptoms and treatments of specific illnesses, health data warehouses make it possible, among others, to determine which course of action proves to be the most effective. As the technology offers the possibility to directly improve the delivery of care and care itself, the evaluation must address the use of the system for medical, clinical and nursing purposes.

Component #3C: Research utilization. Health data warehousing provides an explorative way to work with the data. It identifies trends and offers insight in areas that have not yet been investigated. It helps address issues that have not yet been anticipated. It is therefore an ideal candidate for research environments and the use of the system to this end must also be evaluated.

4.4. Net Benefits

Net benefits refer to the positive outcomes, or positive impact, of the data warehouse. Such impact must be assessed at three different levels. The individual level concerns those professionals using the data warehouse in healthcare settings and is measured with metrics such as improved productivity and improved decision effectiveness. The organizational level applies to healthcare organizations and involves measures such as contribution to achieving the organization's goals and increased market

share. The net benefits obtained on an individual and organizational basis in turn positively impact healthcare systems as a whole to create the third level of net benefits.

5. Framework's Theoretical References

In order to conduct the evaluation, the above-mentioned dimensions, components and net benefits must be further broken down into factors.

The DeLone and McLean model uses the terms "measure" and "factor" interchangeably. According to the Oxford dictionary a measure is "a standard or unit of measurement, a standard unit used to express the size, amount or degree of something" (OED, 2007). A factor, on the other hand, is defined as "a circumstance, fact, or influence that contributes to a result" (OED, 2007). The dissertation posits that factors, i.e. the finer grained elements which originate from the dimensions and components must first be defined. Once defined, factors can then be converted into metrics to collect measures on those finer grained elements.

Even though many research studies have been conducted to test and validate the DeLone and McLean model, most of them have brought inconsistent results because they addressed a single dimension of success. The proposed framework seeks inclusiveness and reproducibility, and therefore aims at including all applicable factors for all dimensions.

A review was done of the measures involved in each dimension of the DeLone and McLean model (system quality, information quality, service quality, user satisfaction, use, and net benefits). When applicable, those measures were selected as a basis for the list of factors used in the proposed framework.

Appendix A lists the individual DeLone and McLean measures which were retained and their corresponding factor in the proposed framework. Appendix B lists the factors for which survey items are available and can be adapted from existing studies to conduct the evaluation.

6. Definition of Framework's Factors

This section provides a definition of each of the individual factors and is organized around 5 tables, one for each of the framework's dimensions (organizational dimension, technological dimension, utilization dimension) and one for the individual and organizational net benefits.

Each table includes three columns. The first column lists the identification code of the components, the second column lists the components' definition and the third column lists all relevant factors with their identification code and definition. Table 1 (p.43) addresses the organizational dimension with components such as resources, users' needs assessment and user support along with the corresponding factors such as budget preparation and monitoring, user involvement and training programs. Table 2 (p.44) addresses the technological dimension with components such as architectural choices and performance along with their respective factors such as system flexibility and system use. Tables 3 and 4 (p.46) address the utilization dimension with components such as financial and medical utilization along with their corresponding factors such as purpose of use and user satisfaction. Table 5 (p.50) presents the individual net benefits with factors such as improved task performance and improved decision effectiveness. Table 6 (p.51) presents the organizational net benefits with factors such as increased market share and improved patient safety.

Table 1 provides a definition of the organizational dimension's components and factors. The first column lists the identification code of the components, the second column lists the components' definition and the third column lists all relevant factors with their identification code and definition.

Table 1 – Factors Definition: Organizational Dimension

EVALUATION DIMENSION #1: ORGANIZATIONAL DIMENSION		
	COMPONENTS' DEFINITION	**FACTORS' DEFINITION**
1A	**Legitimate Business Needs** Business opportunities and/or issues facing the healthcare organization and addressed by the data warehouse based on business goals, processes, priorities, and existing entities and systems (Moyer, 2003; Watson & Haley, 1998).	• **1A-1. Project definition**: purpose, goals, scope, objectives, deliverables, constraints and risks of the data warehouse (ACM, 1999; Vatanasombut & Gray, 1999). o **1A-1.1. Project charter**: project definition document (ACM, 1999; Vatanasombut & Gray, 1999). o **1A-1.2. Project plan**: document outlining the project's control and execution (ACM, 1999; Vatanasombut & Gray, 1999). • **1A-2. Targeted areas for process improvement and cost savings**: financial, operational, medical, clinical, nursing, and research areas for which opportunities for process improvement and/or cost savings have been identified (ACM, 1999; Vatanasombut & Gray, 1999). • **1A-3. Targeted timeframe**: period during which the development, implementation and maintenance will take place, including milestones and predicted tasks with their duration and deadlines (ACM, 1999; Vatanasombut & Gray, 1999).
1B	**Management Support** Sponsorship for the data warehouse across management teams and at all corporate levels, including the user level (ACM, 1999; DeWitt & Hampton, 2005; Guida & Mauri, 1993; Rist, 1997; Russom, 2009; Vatanasombut & Gray, 1999).	• **1B-1. Champion**: executive and upper-level management individual(s) who foster(s) the data warehouse and advocate(s) for its furthering (Rist, 1997). • **1B-2. Ownership**: executive and upper-level management individuals and entities which take responsibility for the data warehouse (DeWitt & Hampton, 2005). • **1B-3. Accountability**: duty of the above-mentioned individuals and entities to account for the activities related to the data warehouse and to disclose project results in a transparent fashion (Ballou & Pazer, 1985; Wixom & Watson, 2001). • **1B-4. Openness to opportunities and process improvement**: commitment at the executive and upper-management levels to unveil new opportunities and improve processes (Watson & Haley, 1998).
1C	**Resources** **T**ime, money, equipment, staff and other assets that are drawn on to develop, implement and maintain the data warehouse (Morris, 2010; Mort et al., 2003).	• **1C-1. Budget preparation and monitoring**: estimation over time of the costs, revenues and resources related to the data warehouse in a manner that emphasizes performance measurement and the achievement of quantified objectives (Watson & Haley, 1998; Watson et al., 1999). • **1C-2. Use of one or more of the following ratios and analyses** (Watson & Haley, 1998; Watson et al., 1999): o 1C-2.1. Cost-benefit ratio/analysis, o 1C-2.2. Cost of ownership analysis, o 1C-2.3. Return on assets, ROI analyses, o 1C-2.4. Ratio of net income to operating expenses. • **1C-3. Charges for system use**: association of the use of the data warehouse to charge-back procedures (Watson & Haley, 1998; Watson et al., 1999).
1D	**Users' Needs Assessment** Determination and prioritization of the needs of intended users, and their transformation in functional requirements to be addressed by the data warehouse (Kaplan & Brennan, 2001; Vatanasombut & Gray, 1999).	• **1D-1. Users' profiles**: track record of information related to users' work environment including display and application settings, network connections, and data usage (Ballou & Pazer, 1985). • **1D-2. Initial/subsequent data needs/requests**: assessment of user-specific data needs over time and track record of formal data requests (Bailey & Pearson, 1983). • **1D-3. Initial/subsequent extraction frequency**: track record of the frequency at which data has been extracted by users from the source system over time (Ballou & Pazer, 1985). • **1D-4. Enhancement/change requests**: track record of users' requests for enhancements and/or changes to the data warehouse (Bailey & Pearson, 1983). • **1D-5. Users' involvement**: users' participation in tasks and roles throughout the data warehouse Development Life Cycle (Wixom & Watson, 2001).
1E	**Users' Support** Services provided to users to assist them in learning about and using the data warehouse, and to address issues associated with the use of the data warehouse (DeWitt & Hampton, 2005; Ives et al., 1983; Rist, 1997; Vatanasombut & Gray, 1999).	• **1E-1. Training programs**: short-term and ongoing courses aimed at training users on the features, functionalities and use of the data warehouse, and to enhance the skills of the project team (Bailey & Pearson, 1983). • **1E-2. Documentation**: training manuals, users' guides, and documentation describing the data warehouse, as well as self-paced methods allowing users to practice course content and review instructions on how to use the system (Bailey & Pearson, 1983). • **1E-3. Technical support**: assistance provided by technical professionals to users experiencing difficulties with the data warehouse (Bailey & Pearson, 1983). • **1E-4. Helpdesk**: point of contact providing assistance to users by troubleshooting issues, answering questions and resolving problems by phone, email, or with a tool that logs calls/incidents (Bailey & Pearson, 1983). • **1E-5. Knowledge sharing:** techniques and methods used to build a knowledge base about the data warehouse that can be shared by all individuals involved in the development, maintenance and use of the technology (Bailey & Pearson, 1983). • **1E-6. Project team skills**: technical expertise and interpersonal aptitude of the data warehouse team, including competence, proficiency, empathy, and responsiveness (Bailey & Pearson, 1983; Wixom & Watson, 2001).

Table 2 provides a definition of the technological dimension's components and factors. The first column lists the identification code of the components, the second column lists the components' definition and the third column lists all relevant factors with their identification code and definition

Table 2 – Factors Definition: Technological Dimension

EVALUATION DIMENSION #2: TECHNOLOGICAL DIMENSION		
	COMPONENTS' DEFINITION	**FACTORS' DEFINITION**
2A	**Data** The data warehouse acquires its data from transactional systems and systems external to the organization. For its effective use and to ensure its quality, data must be identified, extracted, transformed, stored and managed in a secure manner (March & Hevner, 2007).	• **2A-1. ETL process/layers**: extraction of the data from the source systems, transformation of the data to conform to the standardized architecture, loading of the data into the data warehouse (Imhoff et al., 2003). o 2A-1.1. Staging layer: storage of the raw data extracted from the source systems. o 2A-1.2. Integration layer: transformation of the data from the staging layer to conform to the standardized architecture. o 2A-1.3. Loading of the transformed data into the operational area of the data warehouse. • **2A-2. Data governance**: procedures and entities involved in the management of data availability, integrity and security. Includes the definition of roles and contributions of data owners/custodians, and the accountability mechanisms applicable to aspects such as data accuracy, accessibility, consistency, completeness, updating, error recovery; to the storage, archival, back-up and security processes; to the standards and procedures related to the use of the data; and to regulatory compliance mechanisms (Miller, 1996). o 2A-2.1. Metadata: comprehensive business documentation of the data (business definitions of the data, fields, cubes, aggregates, datamarts) and technical documentation of the ETL process (rules, transformations, aggregations, mappings) including data models, data dictionary and ETL load statistics (Imhoff et al., 2003). o 2A-2.2. Specification of data format and data elements, use of data standards (Akhtar et al., 2005). o 2A-2.3. Inactive data identification and treatment (Imhoff et al., 2003). • **2A-3. Data accessibility**: extent to which the source systems can be accessed to extract the data,including their disparity and readiness (Ballou & Pazer, 1985). • **2A-4. Data availability**: extent to which the data is available, i.e. present and ready for immediate use in the data warehouse, including the extensiveness, breadth, scope and comprehensiveness of the data marts content (Ballou & Pazer, 1985). • **2A-5. Data completeness**: all needed data elements and records are present in the data warehouse and all values are listed for the concerned variables (Ballou & Pazer, 1985). • **2A-6. Data currency**: extent to which the data in the data warehouse is current and up-to-date (Huh, Keller, Redman, & Watkins, 1990). • **2A-7. Data integrity**: extent to which the data warehouse ensures the following attributes at all times: o 2A-7.1. Data accuracy: recorded values correspond to actual ones (Ballou & Pazer, 1985). o 2A-7.2. Data consistency: instances of recorded values do not vary and yield similar results in similar analyses (Fisher & Kingma, 2001). o 2A-7.3. Data validity: extent to which values correspond to those established for the data warehouse domain (Ballou & Pazer, 1985). o 2A-7.4. Data correctness: recorded values are free from error and exact (Ballou & Pazer, 1985). • **2A-8. Data relevance**: the data in the data warehouse has a logical and sensible relationship to the findings it supports (Bailey & Pearson, 1983). • **2A-9. Data reliability**: overall dependability of the data available in the data warehouse, and extent to which it is convincing for its purpose and context (Ahituv, 1980; Bailey & Pearson, 1983; Miller & Doyle, 1987).
2B	**Architectural choices** Choices made regarding the design and contents of the data warehouse in order to deliver services to users by optimizing the system's structures and technical framework according to the predefined business processes and rules (Russom, 2009).	• **2B-1. System flexibility**: capacity of the data warehouse to support complex data types, perform aggregations from multiple sources, handle multiple platforms, languages and operating systems, and adapt to new conditions, circumstances and requests (Bailey & Pearson, 1983; Miller & Doyle, 1987). • **2B-2. System scalability**: capacity of the data warehouse to allow for additional data storage, increased CPU power and memory, and capacity to leverage newer technology such as Hadoop and NoSQL (Russom, 2011). • **2B-3. System sophistication**: degree of complexity, inclusiveness, and technical advancement of the data warehouse. • **2B-4. Security rules**: methods and procedures regarding system access and use, including rules protecting the data and its transfer against misappropriation, unauthorized alteration and loss (Bailey & Pearson, 1983; Lumpkin, 2000). • **2B-5. Privacy rules**: methods and procedures protecting identifiable health information, and compliance with regulations protecting patients' privacy (Lumpkin, 2000). • **2B-6. Mix vendor/custom-designed applications**: proportions of "off-the shelf" vs. "in-house" applications. • **2B-7. Early and on-going generation of value**: capacity of the data warehouse to support the introduction of new products and the generation of results in an incremental and on-going fashion (Russom, 2011).

Table 2 (cont'd) – Factors Definition: Technological Dimension

EVALUATION DIMENSION #2: TECHNOLOGICAL DIMENSION (CONT'D)		
	COMPONENTS' DEFINITION	**FACTORS' DEFINITION**
2C	**Technological choices** Choices made with regard to hardware, software, methods and programs needed to operate the data warehouse and deliver enterprise data analytics and business intelligence (Lumpkin, 2000; Russom, 2009).	• **2C-1. Application portfolio**: set of tools that constitute the health data warehouse (Imhoff et al., 2003): o 2C-1.1. Data modeling and profiling tools; o 2C-1.2. Metadata management tools; o 2C-1.3. ETL tools (including engineering strategies for extraction, transformation, loading and indexing); o 2C-1.4. Storage tools; o 2C-1.5. Front-end tools: query and reporting tools, including SQL, OLAP cubes, web reporting, scorecards, data mining, GSI; o 2C-1.6. Integration of newer technologies such as Hadoop and NoSQL; and o 2C-1.7. Integration of all applications into a coherent and efficient system.
2D	**Performance** Manner in which the health data warehouse operates, and quality of its functioning, including how well and how fast it addresses the needs of its users (Fisher & Kingma, 2001).	• **2D-1. System reliability**: overall dependability of the data warehouse (Bailey & Pearson, 1983; Miller & Doyle, 1987). o 2D-1.1. Response/turnaround time: time needed to return a complete output to a given request (Imhoff et al., 2003). o 2D-1.2. Updates/refresh rate: data extracts' schedule, facts/dimensions tables' update, and overall refreshment periodicity of the data warehouse content (Imhoff et al., 2003; Russom, 2011). o 2D-1.3. Loading failures: ETL defects impacting the loading of the data to the data warehouse (Imhoff et al., 2003; Russom, 2011). o 2D-1.4. System availability and use: proportion of operational time ("downtime" vs. "uptime"), and type, amount, nature and duration of use (Russom, 2011). • **2D-2. Concurrency capability**: capacity of the data warehouse to carry out concurrent operations such as executing simple and complex queries, producing reports, extracting data and loading new content successfully in a timely fashion (Russom, 2011).

Table 3 provides a definition of the factors shared by these three components. The first column lists the identification code of the components, the second column lists the components' title and the third column lists all relevant factors with their identification code and their definition.

Table 3 – Factors Definition: Utilization Dimension - Factors Shared by All Components

EVALUATION DIMENSION #3: UTILIZATION DIMENSION		
	COMPONENTS' DEFINITION	**FACTORS' DEFINITION**
3A 3B 3C	**Financial and Operational Utilization** Use of the analytics provided by the data warehouse in operational and financial areas, and to support department- and organization-wide strategies to optimize processes and resources utilization, and reduce operating costs. **Medical, Clinical, Nursing Utilization** Use of the analytics provided by the data warehouse in medical, clinical and nursing areas to optimize diagnoses, treatments, and care processes. **Research Utilization** Use of the data warehouse's analytics to generate scientific knowledge and develop new processes, products and techniques with regard to diagnoses, treatments and healthcare delivery.	• **3A/B/C-1. Front-end tools**: utilization of the front-end tools of the data warehouse by users. • **3A/B/C-1.1. Amount of use**: how many users are there and how much do they utilize the front-end tools, i.e. number of tools used, proportion of utilization among them and frequency of use; number of reports and dashboards downloaded, number of queries made, amount of data used (Agarwal & Prasad, 1997; Doll & Torkzadeh, 1998). • **3A/B/C-1.2. Duration of use**: length of average session and period of time during which the front-end tools have been in existence (Agarwal & Prasad, 1997; Doll & Torkzadeh, 1998; Karahanna, Straub, & Chervany, 1999). • **3A/B/C-1.3. Motivation of use**: given their needs and expectations, and the presence/absence of incentives, factors that prompt users to utilize the front-end tools, i.e. their interest, commitment and level of effort to use them (Agarwal & Prasad, 1997; Doll & Torkzadeh, 1998; Karahanna et al., 1999). • **3A/B/C-1.4. Nature of use:** inherent character of the use, i.e. recurring or sporadic, direct or chauffeured, resulting of a routine or exploratory, actual or reported, and including the proportion of each type of use (Agarwal & Prasad, 1997; Doll & Torkzadeh, 1998; Karahanna et al., 1999). • **3A/B/C-1.5. Ease of Use**: ease with which users can learn about and use the front-end tools. ▪ 3A/B/C-1.5.1.Ease of learning: extent to which the front-end tools are perceived by users as easy to learn (Igbaria et al., 1997). ▪ 3A/B/C-1.5.2. Ease of use after learning: extent to which the front-end tools are perceived by users as easy to use after proper training (Larsen & Wetherbe, 1999). ▪ 3A/B/C-1.5.3.Usability: • 3A/B/C-1.5.3A. User-centeredness: extent to which the interfaces meet users' mental models, tasks and requirements (Igbaria et al., 1997; Larsen & Wetherbe, 1999). • 3A/B/C-1.5.3B. Effectiveness: extent to which users' goals are met by the front-end tools, and interfaces offer built-in user assistance and present understandable and unambiguous paths (Straub et al., 1995; Taylor & Todd, 1995). • 3A/B/C-1.5.3C. Efficiency: extent to which users can complete the tasks involving the front-end tools fast (Straub et al., 1995; Taylor & Todd, 1995). • 3A/B/C-1.5.3D. Engagement: extent to which the style of the visual presentation, the design and readability of as well as interaction with the front-end tools are perceived by users as pleasant and appropriate to the tasks (Igbaria et al., 1997; Larsen & Wetherbe, 1999). • 3A/B/C-1.5.3E. Error tolerance: extent to which users perceive the front-end tools as preventing errors from occurring over the course of an interaction, and as effective at recovering from errors when they occur (Igbaria et al., 1997; Larsen & Wetherbe, 1999). • **3A/B/C-1.6. Usefulness**: extent to which the front-end tools are of applicability, use, service, help and benefit. (Bovee et al., 2003; Kahn et al., 2002). • **3A/B/C-2. Output information**: information is the accumulation of transactional data into a meaningful context and is provided to users in the form of reports and metrics made available through the front-end tools. o **3A/B/C-2.1. Accuracy**: correctness of the output information, i.e. extent to which it is error-free (Bailey & Pearson, 1983; Bovee, Srivastava, & Mak, 2003; Kahn, Strong, & Wang, 2002; Miller, 1996). o **3A/B/C-2.2. Appearance**: visible aspects of the output information including: ▪ 3A/B/C-2.2.1. Format: material form of the output information and ways in which it is made available, i.e. reports, dashboards, raw data, electronic/print form (Bailey & Pearson, 1983). ▪ 3A/B/C-2.2.2. Display: ways in which the output information is laid out, i.e. schematic design, type and composition; provision of tables, graphs and charts. ▪ 3A/B/C-2.2.3. Clarity: extent to which the output information is clear, unambiguous, unequivocal and explicit (Bailey & Pearson, 1983). ▪ 3A/B/C-2.2.4. Readability: extent to which the output information is legible (Bailey & Pearson, 1983). o **3A/B/C-2.3. Comparability**: ways in which the output information lends itself to the examination of alternatives and comparative analysis. o **3A/B/C-2.4. Completeness**: extensiveness and comprehensiveness of the output information so that it includes all elements needed by users (Bailey & Pearson, 1983; Bovee et al., 2003; Kahn et al., 2002).

Table 3 (cont'd) – Factors Definitions: Utilization Dimension - Factors Shared by All Components

EVALUATION DIMENSION #3: UTILIZATION DIMENSION (CONT'D 1)		
	COMPONENTS' DEFINITION	**FACTORS' DEFINITION**
3A 3B 3C	**Financial and Operational Utilization** Use of the analytics provided by the data warehouse in operational and financial areas, and to support department- and organization-wide strategies to optimize processes and resources utilization, and reduce operating costs. **Medical, Clinical, Nursing Utilization** Use of the analytics provided by the data warehouse in medical, clinical and nursing areas to optimize diagnoses, treatments, and care processes. **Research Utilization** Use of the data warehouse's analytics to generate scientific knowledge and develop new processes, products and techniques with regard to diagnoses, treatments and healthcare delivery.	o **3A/B/C-2.5. Conciseness**: extent to which the output information is brief and succinct but yet comprehensive (Fisher & Kingma, 2001; Bovee et al., 2003; Kahn et al., 2002). o **3A/B/C-2.6. Consistency**: extent to which the facts, forms and characteristics of the output information yield similar results for similar analyses and can be asserted together without contradiction (Fisher & Kingma, 2001). o **3A/B/C-2.7. Currency**: degree to which the output information is current and up-to-date (Huh et al., 1990). o **3A/B/C-2.8. Importance**: significance and value of the output information (Bovee et al., 2003; Kahn et al., 2002). o **3A/B/C-2.9. Informativeness**: extent to which the output information is instructive and increases knowledge. o **3A/B/C-2.10. Precision**: extent to which the output information is exact and clearly delineated (Bovee et al., 2003; Kahn et al., 2002). o **3A/B/C-2.11. Quantitativeness**: extent to which the output information pertains to quantities and measures. o **3A/B/C-2.12. Relevance**: degree of congruence between users' requests and the output information (Bailey & Pearson, 1983; Bovee et al., 2003; Kahn et al., 2002). o **3A/B/C-2.13. Reliability**: overall dependability of the output information, i.e. its consistency regardless of the front-end tool used (Bailey & Pearson, 1983; Miller & Doyle, 1987). o **3A/B/C-2.14. Sufficiency**: extent to which the amount of information provided by the front-end tools is adequate. o **3A/B/C-2.15. Timeliness**: extent to which the output information is available at an opportune time for its use (Bailey & Pearson, 1983; Barki & Huff, 1985; Ives et al., 1983). o **3A/B/C-2.16. Understandability**: extent to which the output information is intelligible and comprehensible. o **3A/B/C-2.17. Uniqueness**: extent to which the output information presents a single version of the truth. o **3A/B/C-2.18. Usefulness**: extent to which the output information is of applicability, use, service, help and benefit (Bovee et al., 2003; Kahn et al., 2002). o **3A/B/C-2.19. Validity:** extent to which the output information reflects the underlying reality and satisfies agreed upon standards (Miller, 1996). o **3A/B/C-2.20. Volume**: amount of information made available to users, i.e. number of outputs and size of their content (Bailey & Pearson, 1983). • **3A/B/C-3. System Service**: support provided to users when they use the front-end tools (Bailey & Pearson, 1983). o **3A/B/C-3.1. Change requests process**: ways in which (manner, method, time) the data warehouse team handles users' requests for changes to existing aspects of the data warehouse and/or services. o **3A/B/C-3.2. New development requests process**: ways in which (manner, method, time) the data warehouse team handles users' requests for new applications and/or services. o **3A/B/C-3.3. Customer relations**: ways in which the data warehouse team handles interactions with users, i.e. methods and conduct. • **3A/B/C-4. User satisfaction**: degree to which the needs and expectations of users are met by the front-end tools. • **3A/B/C-4.1. Overall**: level of users' satisfaction with the front-en tools and output information in general. • **3A-4.2. Specific**: level of users' satisfaction with the following specifics: ▪ 3A/B/C-4.2.1. Specific front-end tools or aspects thereof (Saarinen, 1996). ▪ 3A/B/C-4.2.2. Specific components of the front-end tools that aid with decision-making (Saarinen, 1996). ▪ 3A/B/C-4.2.3. Specific aspects of the output information (Li, 1997). • **3A/B/C-4.3. Enjoyment**: extent to which novice and expert users enjoy using the front-end tools (Goodhue & Thompson, 1995). • **3A/B/C-4.4. Anxiety factor**: extent to which the front-end tools induce anxiety issues such as the fear of losing large amount of work without notice (Seddon & Kiew, 1994).

Table 4 provides a definition of the factors specific to each of the three utilization components. The first column lists the identification code of the components, the second column lists the components' title and the third column lists all relevant factors with their identification code and their definition.

Table 4 – Factors Definition: Utilization Dimension - Factors Specific to Each Component

EVALUATION DIMENSION #3: UTILIZATION DIMENSION (CONT'D 2)		
	COMPONENTS' DEFINITION	**FACTORS' DEFINITION**
3A	**Financial and operational utilization** Financial and operational areas for which the data warehouse is used and proportion of use between them (Agarwal & Prasad, 1997; Doll & Torkzadeh, 1998).	• **3A-5. Purpose of use**, including: o 3A-5.1. Cost reductions, o 3A-5.2. Fraud detection, o 3A-5.3. Leverage of payer incentive programs, o 3A-5.4. Process improvement, o 3A-5.5. Revenue cycle management, o 3A-5.6. Regulatory compliance, o 3A-5.7. Regulatory reporting, o 3A-5.8. Resources utilization, o 3A-5.9. Waste management.
3B	**Medical/clinical/nursing utilization** Medical, clinical and nursing areas for which the data warehouse is used and proportion of use between them (Agarwal & Prasad, 1997; Doll & Torkzadeh, 1998).	• **3B-5. Purpose of use**, including: o 3B-5.1. Admission rates reduction, o 3B-5.2. Care management, o 3B-5.3. Care process improvement, o 3B-5.4. Customer relationship management, o 3B-5.5. Diagnosis optimization, o 3B-5.6. Disease management, o 3B-5.7. Drug regimen optimization, o 3B-5.8. Errors detection and management, o 3B-5.9. Hospital-acquired infection rates reduction, o 3B-5.10. Leverage of protocols and best practices, o 3B-5.11. Occupancy/capacity optimization, o 3B-5.12. Patient throughput tracking, o 3B-5.13. Readmission rates reduction, o 3B-5.14. Reduction of practice patterns variations, o 3B-5.15. Risk identification/adjustment, o 3B-5.16. Severity identification/adjustment, o 3B-5.17. Shortening of length-of-stay, o 3B-5.18. Shortening of waiting time, o 3B-5.19. Treatment effectiveness, o 3B-5.20. Treatment standardization, o 3B-5.21. Workflow improvement.

Table 4 (cont'd) – Factors Definition: Utilization Dimension, Factors Specific to Each Component

EVALUATION DIMENSION #3: UTILIZATION DIMENSION (CONT'D 3)		
	COMPONENTS' DEFINITION	**FACTORS' DEFINITION**
3C	**Research utilization** Research areas for which the data warehouse is used and proportion of use between them (Agarwal & Prasad, 1997; Doll & Torkzadeh, 1998)	• **3C-5. Purpose of use**, including: o 3C-5.1. Behavioral research, o 3C-5.2. Comparative effectiveness research, o 3C-5.3. Development of new medical technologies, o 3C-5.4. Disease-specific research, o 3C-5.5. Epidemiologic research, o 3C-5.6. Evaluation studies, including: ▪ 3C-5.6.1. Information technologies, ▪ 3C-5.6.2. Medical/surgical techniques and equipments, ▪ 3C-5.6.3. Medications, o 3C-5.7. Feasibility studies for grant applications, o 3C-5.8. Health services research, o 3C-5.9. Health outcome research, o 3C-5.10. Patient-oriented research/clinical trials, o 3C-5.11. Public health research, o 3C-5.12. Translational research, o 3C-5.13. Treatment-specific research.

Table 5 provides a definition of the factors pertaining to Individual Net Benefits. The first column lists the identification code of the components, the second column lists the components' title and the third column lists all relevant factors with their identification code and their definition.

Table 5 – Factors Definition: Individual Net Benefits

NET BENEFITS EVALUATION: INDIVIDUAL NET BENEFITS		
	COMPONENTS' DEFINITION	**FACTORS' DEFINITION**
4A 4B 4C	**Financial and Operational Individual Net Benefits** **Medical, Clinical, Nursing Individual Net Benefits** **Research Individual Net Benefits** Positive outcome of the use of the data warehouse and its information output for healthcare organizations' personnel.	• **4A/B/C-1. Improved information awareness, recall and understanding**: extent to which healthcare organizations' personnel have become aware of information they did not know existed, have been able to bring back older information to the forefront, and overall have been able to better understand available information (Goodhue & Thompson, 1995; Guimaraes & Igbaria, 1997). • **4A/B/C-2. Improved ability to identify problems**: extent to which healthcare organizations' personnel have been able to unveil new issues (Guimaraes & Igbaria, 1997). • **4A/B/C-3. Improved ability to interpret issues accurately**: extent to which healthcare organizations' personnel have increased their ability to correctly analyze given issues (Teng & Calhoun, 1996). • **4A/B/C-4. Improved task performance**: extent to which healthcare organizations' personnel have become more proficient with the activities that formally define their position (Igbaria & Tan, 1997; Teng & Calhoun, 1996). • **4A/B/C-5. Improved productivity**: extent to which healthcare organizations' personnel have become more productive, i.e. are able to accomplish more and bring more results (Igbaria & Tan, 1997; Teng & Calhoun, 1996). • **4A/B/C-6. Increased power and/or influence**: extent to which healthcare organizations' personnel have been empowered in their position and able to influence the decision-making process (Torkzadeh & Doll, 1999). • **4A/B/C-7. Triggering of management action**: extent to which healthcare otganizations personnel have been able to prompt upper management and executives to act upon issues they had brought to their attention (Weill & Vitale, 1999; Yuthas & Young, 1998). • **4A/B/C-8. Improved decision effectiveness**: extent to which the effectiveness of the decisions made by healthcare organizations' personnel have improved (Weill & Vitale, 1999; Yuthas & Young, 1998), including: o 4A/B/C-8.1. Better understanding of the decision context, o 4A/B/C-8.2. Improved analysis capability, o 4A/B/C-8.3. Increased confidence in decisions, o 4A/B/C-8.4. Triggering of positive changes in decisions, o 4A/B/C-8.5. Increased correctness of decisions, o 4A/B/C-8.6. Increased quality of decisions, o 4A/B/C-8.7. Shortened time to decisions, o 4A/B/C-8.8. Increased decision-making participation. • **4A/B/C-9. Learning**: extent to which healthcare organizations' personnel have been able to generate new knowledge through the collection and analysis of evidence (Guimaraes & Igbaria, 1997). • **4A/B/C-10. Innovation**: extent to which healthcare organizations' personnel have been able to try out innovative ideas and concepts (Guimaraes & Igbaria, 1997).

Table 6 provides a definition of the factors pertaining to Organizational Net Benefits. The first column lists the identification code of the components, the second column lists the components' title and the third column lists all relevant factors with their identification code and their definition.

Table 6 – Factors Definition: Organizational Net Benefits

NET BENEFITS EVALUATION: ORGANIZATIONAL NET BENEFITS		
	COMPONENTS' DEFINITION	**FACTORS' DEFINITION**
5A	**Financial and Operational Organizational Net Benefits** Positive outcome of the use of the data warehouse and its information output for healthcare organizations from a financial and operations standpoint.	• 5A-1. Contribution to achieving the organization's goals and mission (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5A-2. Costs reductions, including operating cost and staff reductions (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5A-3. Improved resources utilization, • 5A-4. Improved waste management, • 5A-5. Improved revenue cycle management, • 5A-6. Improved leverage of payer incentive programs, • 5A-7. Improved regulatory compliance, • 5A-8. Improved regulatory reporting, • 5A-9. Increased market share (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5A-10. Increased profits (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5A-11. Increased revenue (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5A-12. Increased work volume (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5A-13. Process improvements, • 5A-14. Productivity gains (Martinsons et al., 1999 ; Mirani & Lederer, 1998).
5B	**Medical/Clinical/Nursing Organizational Net Benefits** Positive outcome of the use of the data warehouse and its information output for healthcare organizations from a medical, clinical and nursing standpoint.	• 5B-1. Contribution to achieving the organization's goals and mission (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5B-2. Costs reductions, including operating cost and staff reductions (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5B-3. Improved resources utilization, • 5B-4. Improved waste management, • 5B-5. Improved leverage of payer incentive programs, • 5B-6. Improved regulatory compliance, • 5B-7. Improved regulatory reporting, • 5B-8. Improved healthcare services effectiveness, including access, convenience and timeliness, • 5B-9. Improved healthcare delivery efficiency, • 5B-10. Improved healthcare quality, • 5B-11. Improved patient safety, • 5B-12. Improved healthcare outcomes, • 5B-13. Increased patient satisfaction, • 5B-14. Increased market share (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5B-15. Increased profits (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5B-16. Increased revenue (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5B-17. Increased work volume (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5B-18. Process improvements, • 5B-19. Productivity gains (Martinsons et al., 1999; Mirani & Lederer, 1998).

Table 6 (cont'd) – Factors Definition: Organizational Net Benefits

NET BENEFITS EVALUATION: ORGANIZATIONAL NET BENEFITS (CONT'D)		
	COMPONENTS' DEFINITION	**FACTORS' DEFINITION**
5C	**Research Organizational Net Benefits** Positive outcome of the use of the data warehouse and its information output for healthcare organizations from a research standpoint.	• 5C-1. Contribution to achieving the organization's goals and mission (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5C-2. Contribution to: o 5C-2.1. Behavioral research, o 5C-2.2. Comparative effectiveness research, o 5C-2.3. Development of new medical technologies, o 5C-2.4. Disease-specific research, o 5C-2.5. Epidemiologic research, o 5C-2.6. Evaluation studies, including information technologies, medical/surgical techniques and equipments, medications, o 5C-2.7. Feasibility studies for grant applications, o 5C-2.8. Health services research, o 5C-2.9. Health outcome research, o 5C-2.10. Patient-oriented research/clinical trials, o 5C-2.11. Public health research, o 5C-2.12. Translational research, o 5C-2.13. Treatment-specific research, • 5C-3. Costs reductions, including operating cost and staff reductions (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5C-4. Improved resources utilization, • 5C-5. Improved waste management, • 5C-6. Improved healthcare services effectiveness, including access, convenience and timeliness, • 5C-7. Improved healthcare delivery efficiency, • 5C-8. Improved healthcare quality, • 5C-9. Improved patient safety, • 5C-10. Improved healthcare outcomes, • 5C-11. Increased patient satisfaction, • 5C-12. Increased market share (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5C-13. Increased profits (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5C-14. Increased revenue (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5C-15. Increased work volume (Martinsons et al., 1999; Mirani & Lederer, 1998), • 5C-16. Process improvements, • 5C-17. Productivity gains (Martinsons et al., 1999; Mirani & Lederer, 1998).

CHAPTER IV – EMPIRICAL STUDY DESIGN

An empirical study was conducted to investigate the state of health data warehousing evaluation and the use of the system to improve healthcare efficiency, as well as to compare the findings with the proposed framework. The term "empirical" is considered in a generic fashion and designates the acquisition of knowledge through observation, i.e. the collection and analysis of evidence to address a series of research question. This process is considered "empirical" as opposed to the theoretical framework presented earlier.

1. Methodology

1.1. Exploration Research

The etymology of exploration is the Latin verb "explorare" which means investigate, search out, examine, explore. In research, it describes an approach that can take three different forms. Investigative exploration is the exploratory study and analysis of a topic or phenomenon. It is an inquisitive process that is used for evaluation purposes and to screen alternatives to determine which of several options is most applicable or best to pursue (Shaffir & Stebbins, 1991; Stebbins, 2001). Diagnostic exploration is conducted to gather data on a topic for which little research and/or knowledge is available or to "diagnose" the aspects of a phenomenon to be addressed by subsequent research projects. In this instance, the researcher knows what to investigate and uses the approach to methodically examine the topic or issue under consideration (Shaffir & Stebbins, 1991; Stebbins, 2001). Innovative exploration is used when the purpose of the research is to investigate a topic by means of testing or experimentation to create a particular effect or generate new ideas (Shaffir & Stebbins, 1991; Stebbins, 2001).

The topic investigated exemplifies the second approach, diagnostic exploration. Only a handful of articles had been published on the topic of health data warehousing evaluation. If information systems success had been investigated, very few empirical studies had addressed the evaluation of data warehousing. Most importantly, they had not been conducted in the healthcare sector. Similarly, if a theoretical model

was available, it addressed the success of information systems rather than their evaluation. The methods described in the following sections not only enabled the collection and analysis of the data necessary to further investigate the topic under study but they allowed comparing the proposed framework to current practices.

1.2. Exploration Research Techniques

Exploration research does not lead to precise measurements or quantification. Rather, it provides meaningful characterizations, interpretations and descriptions. Literature review can be used to this effect. This aspect of exploration research is critical since it demonstrates that little or no knowledge is available on the topic under consideration and that an open-ended approach to data collection is justified (Shaffir & Stebbins, 1991; Stebbins, 2001). Experience surveys can also be used and aim at interviewing knowledgeable individuals who have personal experience in the field. Focus groups are free-flowing in nature and a type of interviews which involve a small number of individuals brought together by a moderator to talk about the specified topic. Participants in such groups are exposed to the ideas of others and are encouraged to respond to those ideas with their own. Group interaction is central to focus groups and distinguishes this method from standard interviews. In-depth interviews, unstructured or semi-structured, require the interviewer to interact with one respondent at a time by asking several open-ended questions and probing for in-depth answers (Shaffir & Stebbins, 1991; Stebbins, 2001). Case studies aim at obtaining information from one or a few situations that are representative of the context under consideration. Case studies include examining existing records, observing phenomena as they occur as well as conducting interviews and/or focus groups to study what is happening in a given situation (Shaffir & Stebbins, 1991; Stebbins, 2001).

A literature review was conducted not only on health data warehousing evaluation but also on the assessment of the technology in sectors other than healthcare. The results of these reviews demonstrated that very limited knowledge was available on the topic and that further investigation was required. The empirical study attempted to bridge such gap and to do so it utilized a qualitative method: semi-structured interviews.

2. Participants

The research was conducted in collaboration with the Healthcare Data Warehousing Association (HDWA), a platform founded in 2001 to share ideas and lessons learned in health data warehousing and business intelligence. From Intermountain Healthcare to the US Department of Veteran Affairs and Johns Hopkins Medicine, HDWA counts over 500 healthcare organizations planning or engaged in health data warehousing projects across North America. Through the Association, access was granted to the designated Primary Contacts for each HDWA organization and to those additional members that had not specified a Primary Contact within their organization. The targeted population consisted of healthcare organizations' personnel working in mid- to upper-level management capacity on the development and implementation of health data warehousing. The targeted organizations were single or multi-state health systems as well as medical institutions directly or indirectly involved in education and research.

3. Recruitment

A recruitment email was sent on behalf of the researcher by a member of HDWA's Advisory Board to the designated Primary Contacts providing them with an overview of the study and inviting those interested in participating in the study to reply to the researcher (Appendix C).

The researcher acknowledged receipt of participants' expression of interest and emailed them a consent form (Appendix D) which they were asked to sign and return prior to the interview. Participants were informed that identifiable data would not be disclosed, that participation was voluntary, and that the decision to withdraw could be made at any time. Participants were also informed that providing their answers would imply consent for the researcher to use these responses.

4. Setting

Respondents who agreed to participate were interviewed by telephone by the researcher at a date and time most convenient to them.

5. Data Collection

The interviews were semi-structured in nature, i.e. based on an interview guide but flexible enough to allow respondents to expand on their perception of the technology's assessment (Gubrium & Holstein, 2002; Jackson & Verberg, 2007; Kvale & Brinkmann, 2009).

The interview guide was constructed to mirror the research questions (Table 7) and was reviewed for final approval by the members of the researcher's Supervisory Committee. The final product involved 23 questions and the interviews took on average 43 minutes to conduct.

All interviews were audio recorded using a digital voice recorder offering high acoustic quality and high capacity with several hours of uninterrupted recording as well as direct transfer to a computer for storage and analysis purposes (Gubrium & Holstein, 2002; Jackson & Verberg, 2007; Kvale & Brinkmann, 2009).

The aim of qualitative research is the provision of in-depth and detailed analysis. To achieve this goal, qualitative research relies on small samples the size of which is determined by purpose rather than random. In the absence of clear consensus on sample size, sampling usually follows the principle of saturation. According to this principle, data collection is pursued until it can be determined that no new data is forthcoming. If conceptual gaps are identified, either because of the occurrence of themes that have not been heard yet or because of the emergence of concepts that contradict previous analysis, the sample must be expanded to further study such themes. Once data redundancy is reached, further investigation is no longer necessary and the analysis process ends. In this study, data was deemed redundant and saturation was reached at the 21st interview (Miles & Huberman, 1994).

6. Ethics Approval

An application for ethics review was submitted to the Human Research Ethics Board of the University of Victoria on June 27, 2013. Ethics approval was granted on August 13, 2013 and data collection took place from September 21 to November 22, 2013.

Table 7 – Interview Guide

INTERVIEW GUIDE
DEMOGRAPHIC AND BACKGROUND QUESTIONS
1. What is your DOB? 2. Indicate your role and title in the institution or organization
1: WHAT IS THE STATE OF HEALTH DATA WAREHOUSING EVALUATION?
1.1. What type of data warehousing has your organization undertaken? Do you have a mix of vendor and non-vendor components? Please describe. 1.2. In your organization is the health data warehouse evaluated? If yes, please describe, if no, why? Do you refer to critical success factors when you evaluate, if so what are those factors? 1.3. Does the data warehouse project have specific business goals? If so, what are they? 1.4. Is there widespread sponsorship for the data warehouse project across the organization? 1.5. What is the level of resourcing for the data warehouse project(s) (i.e. time, money, staff, equipment)? Is it sufficient? 1.6. Were user needs assessment conducted as a basis for the data warehouse? Have the user needs been addressed by the system? 1.7. How do you evaluate the costs of doing data warehousing? (e.g. do you perform a financial evaluation of the data warehouse)? If yes, how? 1.8. How do you evaluate the benefits of using a data warehouse (e.g. evaluating improvements in effectiveness, efficiency, etc.)? 1.9. What is the level of support provided to users? (e.g. training, technical support, helpdesk, knowledge sharing)? 1.10. In your organization, is health data warehouse evaluation perceived as necessary?
2: HOW IS DATA WAREHOUSING USED TO IMPROVE HEALTHCARE EFFICIENCY?
2.1. In your organization, is data warehousing used to address inefficiencies and waste? If yes, please describe. If no, why is it so? 2.2. In your organization, is health data warehousing used to improve processes and reduce costs? If yes, please describe. If no, why is it so? 2.3. In your organization, is data warehousing used to address medical, clinical, nursing and research purposes? If yes, please describe. If no, why is it so? 2.4. In which area(s) is your organization's data warehouse producing the most significant results? Why is it so and why are the other areas lagging behind? 2.5. Could identical results be obtained if the data warehouse was not in existence and does this justify having a data warehouse?
3: HOW SHOULD THE EVALUATION OF HEALTH DATA WAREHOUSING BE CONDUCTED?
3.1. When evaluating a health data warehouse, which dimensions and factors should be considered? 3.2. When evaluating a health data warehouse, which methods should be used? 3.3. How do you evaluate the quality of the data in the data warehouse? (e.g. availability, relevance, reliability of data) 3.4. How do you evaluate the effectiveness of the architecture of the data warehouse? (e.g. flexibility, scalability, integration with other systems 3.5. How do you evaluate the early and ongoing generation of value provided by the data warehouse? 3.6. How do you evaluate the technical effectiveness of the components of the data warehouse? 3.7. How do you evaluate the usage, usefulness, usability and performance of the data warehouse? (e.g. who the uses are – type of users, number of users, speed, failure rate, system availability) 3.8. Are you aware of user issues, problems and satisfaction level? How do you become aware of such issues? (e.g. issues with front end tools, reporting systems, the usefulness of information output etc.)

7. Data Analysis

Coherence and order must be brought to the unstructured data collected through interviews. To do this, qualitative data analysis follows an iterative process by which data is continuously examined as it is collected. This process ends with the review of all previous conclusions and the clustering of data with similar meaning.

All recorded interviews were transcribed by the researcher and transcripts were coded using a qualitative analysis software package (NVivo, QSR International).

A code is a label used to identify segments of content, be it paragraphs, sentences or words. The coding process, i.e. systematically assigning codes to content, enables the categorization of key concepts (Miles & Huberman, 1994). Codes can be developed in an inductive or deductive fashion. When developed inductively, codes are assigned by reviewing content line by line for emerging themes. As more content is reviewed, segments that have been assigned the same code are compared and codes are reassessed accordingly. This process is favored by grounded theorists and is said to mirror "the ground," i.e. participants' experiences (Glaser & Strauss, 1967). With the deductive approach, a coding structure is defined prior to reviewing content. Not only does such a preliminary structure render the analytical process more explicit but the process is more strongly informed by a priori reasoning, either from the literature or from existing and/or developed theories (Miles & Huberman, 1994). The coding scheme applied to the empirical study in this dissertation integrated both approaches. A set of predetermined codes was established that focused on the key aspects of the investigation and the comparison of the framework with current practices. These codes evolved over time as content was reviewed. More importantly, codes were added to enable the analysis of new themes which emerged from the interviews.

7.1. Preliminary Coding Structure

A series of 28 codes and 13 sub-codes were determined prior to conducting the interviews. As shown in Table 8, codes and sub-codes were produced with regard to the research question on the state of health data warehousing evaluation and its corresponding questions in the interview guide. These codes also reflected the technical and organizational dimensions of the proposed framework and their corresponding factors. As shown in Table 9, codes were produced with regard to the research question on the utilization of health data warehousing to improve healthcare efficiency and its corresponding questions in the interview guide. These codes also reflected the utilization dimension of the proposed framework and its corresponding factors.

Table 8 Preliminary Coding – Interview Guide Questions 1.1. to 1.10.

STATE OF HEALTH DATA WAREHOUSING EVALUATION Research Question 1, Interview Guide Questions 1.1 to 1.10				
CODES	**SUB-CODES**	**INTERVIEW GUIDE**	**FRAMEWORK DIMENSION**	**FRAMEWORK FACTOR**
Type of data warehouse		Question 1.1.	Technical dimension	2C-1. Application portfolio
Vendor mix		Question 1.1.	Technical dimension	2B-6. Mix vendor/customized applications
Critical success factors		Question 1.2.	N/A	N/A
Business goals		Question 1.3.	Organizational dimension	1A. Legitimate business needs
Sponsorship		Question 1.4.	Organizational dimension	1B. Management support
Resources		Question 1.5.	Organizational dimension	1C. Resources
User needs assessments		Question 1.6.	Organizational dimension	1D. User needs assessments
Financial evaluation		Question 1.7.	Organizational dimension	1C-2. Ratios and analyses
Benefits evaluation		Question 1.8.	Organizational dimension	1C-2. Ratios and analyses
User support		Question 1.9.	Organizational dimension	1E. User support
	Training	Question 1.9.	Organizational dimension	1E-1. Training programs
	Technical support	Question 1.9.	Organizational dimension	1E-3. Technical support
	Helpdesk	Question 1.9.	Organizational dimension	1E-4. Helpdesk
	Knowledge sharing	Question 1.9.	Organizational dimension	1E-5. Knowledge sharing
TOTAL: 10	**TOTAL: 4**			

Table 9 Preliminary Coding – Interview Guide Questions 2.1. to 2.5.

USE OF HEALTH DATA WAREHOUSING TO IMPROVE HEALTHCARE EFFICIENCY Research Question 2, Interview Guide Questions 2.1 to 2.5				
CODES	**SUB-CODES**	**INTERVIEW GUIDE**	**FRAMEWORK DIMENSION**	**FRAMEWORK FACTOR**
Inefficiencies		Question 2.1.	Utlization dimension	N/A
Waste		Question 2.1.	Utlization dimension	3A-5.9. Waste management 5A-4. Improved waste management 5B-4. Improved waste management 5C-5. Improved waste management
Process improvement		Question 2.2.	Utlization dimension	3A-5.4. Process improvement 3B-5.3. Care process improvement 5A-13. Process improvements 5B-18. Process improvements 5C-16. Process improvements
Cost reduction		Question 2.2.	Utlization dimension	3A-5.1. Cost reductions 5A-2. Costs reductions 5C-3. Costs reductions
Medical purpose		Question 2.3.	Utlization dimension	3B-5. Purpose of use
Clinical purpose		Question 2.3.	Utlization dimension	3B-5. Purpose of use
Nursing purpose		Question 2.3.	Utlization dimension	3B-5. Purpose of use
Research purpose		Question 2.3.	Utlization dimension	3C-5. Purpose of use
TOTAL: 8				

Table 10 displays the list of codes and sub-codes which were produced with regard to the research question on how to conduct health data warehousing evaluation and its corresponding questions in the interview guide. These codes also reflected the technical and utilization dimensions of the proposed framework and their corresponding factors.

Table 10 Preliminary Coding – Interview Guide Questions 3.1. to 3.8.

HOW HEALTH DATA WAREHOUSING SHOULD BE EVALUATED Research Questions 3, Interview Guide Questions 3.1 to 3.8				
CODES	**SUB-CODES**	**INTERVIEW GUIDE**	**FRAMEWORK DIMENSION**	**FRAMEWORK FACTOR**
Data quality		Question 3.3.	Technical dimension	2A Data
	Availability	Question 3.3.	Technical dimension	2A-4. Data availability
	Relevance	Question 3.3.	Technical dimension	2A-8. Data relevance
	Reliability	Question 3.3.	Technical dimension	2A-9. Data reliability
Architecture effectiveness		Question 3.4.	Technical dimension	2B Architectural choices
	Flexibility	Question 3.4.	Technical dimension	2B-1. System flexibility
	Scalability	Question 3.4.	Technical dimension	2B-3. System scalability
	System integration	Question 3.4.	Technical dimension	2C-1.7. Integration of all applications
Early generation of value		Question 3.5.	Technical dimension	2B-7. Early generation of value
Performance		Question 3.7.	Technical dimension	2D Performance
	System availability	Question 3.7.	Technical dimension	2D-1.4. System availability and use
	System speed	Question 3.7.	Technical dimension	2D-1.1. Response/turnaround time
	Systeam failure rate	Question 3.7.	Technical dimension	2D-1.3. Loading failures
Usage		Question 3.7.	Utilization dimension	3A/B/C-1.1. Amount of use
Usefulness		Question 3.7.	Utilization dimension	3A/B/C-1.6. Usefulness
Usability		Question 3.7.	Utilization dimension	3A/B/C-1.5.3. Usability
Type of users		Question 3.7.	Utilization dimension	3A. Financial and operational use 3B. Medical, clinical, nursing utilization 3C. Research utilization
Number of users		Question 3.7.	Utilization dimension	3A/B/C-1.1. Amount of use
User satisfaction/issues		Question 3.8.	Utilization dimension	3A/B/C-4. User satisfaction
TOTAL: 10	**TOTAL: 9**			

7.2. Intermediate Coding Structure

The coding scheme evolved over the course of the analysis to capture content from all interviews. Codes were added to cover the interview questions not accounted for in the preliminary coding scheme. With regard to the investigation of the state of health data warehousing evaluation, these codes included whether resources were deemed sufficient, whether an evaluation was performed, whether the evaluation was perceived as necessary, and whether there was reference made to CSFs. With regard to the investigation of the use of health data warehousing, these codes included areas in which the most significant results were produced, areas lagging behind, justification of the data warehouse, and whether

identical results could be obtained without the technology. With regard to the comparison of the framework with current practices, these codes included which dimensions and factors should be considered and which methods should be used.

Sub-codes were developed to reflect the ways in which respondents specifically addressed the questions asked. For example, when respondents were asked about the vendor component of the system, they specified which vendors were used. Sub-codes were created for each vendor. When respondents were asked about the use of the data warehouse to reduce waste, they provided examples in specific areas which were coded as excessive use of blood products, excessive use of implants, unnecessary X-rays, unnecessary lab tests. Sub-codes were created accordingly. When respondents were asked about technical support, they detailed how such support was provided and these aspects were coded as: ticketing system, helpdesk, help email, data steward.

More importantly, codes and sub-codes were developed to address new themes as they emerged from the interviews. For example, as indicated in Chapter V on findings, respondents oftentimes did not address the question asked. A code (topic not addressed) was created to capture this aspect of the study and the data related to it. As indicated in Chapter V on findings, respondents oftentimes were not able to provide precise measures. A code (lack of precise measures) was created to capture this aspect of the study and the data related to it. As indicated in Chapter V on findings and Chapter VI on discussion, respondents provided the reasons why they were not evaluating the system and what took place in lieu of evaluation. Codes were developed to capture these aspects of the study and the data related to it, and included among others, anecdotal evidence, monitoring success vs. evaluation, recognition vs. evaluation, perceived value vs. evaluation.

Of note is the chronology of the codes' development. A significant number of codes were developed very early in the analysis process. This was due to a spontaneous and early alignment of respondents' viewpoint on health data warehousing evaluation – or lack thereof. This alignment was captured in two

ways. With regard to non-emerging themes, it meant recording negative answers very early in the process.

All of the following codes were created as early as the 2nd interview and no later than the 5th:

No evaluation performed: code created by the 2nd interview;

No reference to CSFs: code created by the 2nd interview;

No initial user needs assessment: code created by the 2nd interview;

No follow-up user needs assessment: code created by the 2nd interview;

No financial evaluation performed: code created by the 2nd interview;

No benefits evaluation performed: code created by the 2nd interview;

No data quality evaluation: code created by the 3rd interview;

Evaluation not perceived as necessary: code created by the 5th interview.

It also meant creating codes for emerging themes which provided insight into the above negative answers. All of the following codes were created as early as the 1st interview and no later than the 6th:

Topic not addressed: code created by the 1st interview;

Evolving nature of health data warehousing: code created by the 1st interview;

Lack of precise measures: code created by the 1st interview;

Perceived value vs. evaluation: code created by the 2nd interview;

Recognition vs. evaluation: code created by the 4th interview;

Anecdotal evidence vs. evaluation: code created by the 5th interview;

Monitoring success vs. evaluation: code created by the 6th interview.

Not only were such codes created as early as the 1st interview, but more importantly, the categorization of the data through these codes showed a strong consensus among respondents. The return on new content started to diminish as early as the 15th interview and saturation was reached when interviewing the 21st respondent.

7.3. Final Coding Schemes

The final product consisted of a series of 56 codes and 310 sub-codes. Because of its size, the set of codes required aggregation in order to bring meaningful analysis. To this effect, three categories were created to group the codes and their related sub-codes into aggregates that would later be used to analyze the findings of the empirical study.

First category: Exploratory Coding Scheme. Twenty-five codes along with their 150 sub-codes helped classify content related to the exploratory aspects of the research, i.e. descriptive data related to the system and its organizational context, along with its current evaluation and its use to improve healthcare efficiency. Appendix E displays the list of codes and sub-codes of the exploratory coding scheme.

Second Category: Framework Coding Scheme. Seventeen codes and 142 sub-codes were created to categorize content pertaining to the proposed framework, i.e. descriptive data related to the framework's dimensions and factors as well as respondents' input regarding the content and methods of the evaluation. Appendix F displays the list of codes and sub-codes of the framework coding scheme.

Third Category: Explanatory Coding Scheme. An additional 14 codes and their 18 sub-codes provided the means to sort content that added an explanatory value to the research. These codes pertained to themes which emerged over the course of the interviews and therefore supplemented the codes initially produced to address the interview questions. Appendix G displays the list of codes and sub-codes of the explanatory coding scheme.

7.4. Results Generation

The final stage of the analysis involved generating results. These are not only a product of the above-mentioned codes, but were also obtained by cross-examining the categorized content. This last phase of the analysis was assisted by the query and modeling capabilities of a software package (NVivo, QSR International) that was used to identify trends, uncover patterns, examine relationships in and test categories against the full range of data.

As indicated by the coding schemes and as shown in the next chapter, the research findings lent themselves to a threefold presentation.

Exploration Research. A set of well delineated data emerged from the overall content that clearly addressed the first and second research questions, i.e. “What is the state of health data warehousing evaluation?” (Section 2.1 of Chapter V) and “How is data warehousing used to improve healthcare efficiency?” (Section 2.2. of Chapter V). This data also provided valuable insight into the overall use of health data warehousing (Section 2.3. of Chapter V) and its raison d’être (Section 2.4. of Chapter V).

Framework Comparison. Another set of data was uncovered that directly addressed the third research question, i.e. “How should the evaluation of health data warehousing be conducted?” and enabled the comparison of the framework previously developed to respondents’ input. From user needs assessments to data quality, usage evaluation and assessment methods, Section 3 of Chapter V details how the framework’s dimensions and factors were used by respondents in their respective organization.

Explanatory Factors. An additional set of data was unveiled that, unlike the previous two, did not directly correspond to any research question but rather added an explanatory value to the initial findings. Section 4 of Chapter V demonstrates how anecdotal evidence was considered instead of assessment data, describes the existence of explicit and implicit reasons for the absence of evaluation, and reports what took place in lieu of evaluation and what respondents considered doing in the future.

CHAPTER V - RESEARCH FINDINGS

The following sections present the research findings.

To prevent participants' identification as well as to guarantee confidentiality, respondents are designated in the subsequent sections and chapters by the letter "R" and a number from 1 to 21. As a precautionary measure, these numbers were randomly assigned and do not reflect the order in which participants were interviewed. Similarly, because of the sample size, neither gender nor organizations are identified or explicitly associated with individual responses.

When quantified, results are expressed in percent and/or number of respondents which is symbolized by the letter "n."

1. Sample Characteristics

All respondents were highly skilled, experienced and knowledgeable professionals working in mid- to upper-level management capacities. The organizations they were affiliated with included various types of institutions located across the United States.

1.1. Respondents Demographics

A total of 21 respondents were successfully recruited and agreed to participate in the research. Most of them were males (62%, n=13) between the ages of 42 and 61 (71%, n=15). Most respondents were employed in upper-level management capacities with 43% of them (n=9) holding a Director position and 28% (n=6) acting as Manager. Twenty-four per cent of respondents (n=5) held the title of Data Architect while one respondent (5%) was involved at the executive level. Respondents' roles encompassed technology oversight and strategy (86%, n=18), management (76%, n=16) as well as tasks required for the provision and supervision of BI/Analytics (76%, n=16) or pertaining to architecture (71%, n=15). The technological solutions involved were mainly operational (76%, n=16) and clinical (67%, n=14). Research

solutions were only invoked 48% of the time (n=10) which reflects the nature of the participating organizations.

Table 11 summarizes this information.

Table 11 – Sample Characteristics

SAMPLE CHARACTERISTICS	FREQUENCY (%) (n=21)
Gender Distribution	
Male	62(13)
Female	38(7)
Title Distribution	
Director	43(9)
Manager	28(6)
Data Architect	24(5)
Assistant VP	5(1)
Roles Distribution	
Technical Oversight/Strategy	86(18)
BI/Analytics	76(16)
Management	76(16)
Architect	71(15)
Type of Data Warehouse	
Operational	76(16)
Clinical	67(14)
Research	48(10)

1.2. Organizations' Characteristics

The sample of participating organizations offered a high degree of representativeness in terms of geographical distribution. Institutions were located on both the Atlantic (33%, n=7) and Pacific coasts (24%, n=5) as well as in various states across the continent (43%, n=9). For ease of presentation and to prevent identification, the latter are designated as "mid- and southwest". If most organizations were health systems (50%, n=10), they also included medical centers (30%, n=6) and individual hospitals (20%, n=4). This distribution is quite representative of the American healthcare sector which is dominated by large health systems but also shared with a significant number of university medical centers and fewer highly specialized individual hospitals. Over half of these organizations (55%, n=11) served urban areas, while the other respondents (45%, n=9) covered both rural and urban territories. One organization was a research institution not directly involved in healthcare delivery. Table 12 summarizes this information.

Table 12 – Organizations' Characteristics

ORGANIZATIONS' CHARACTERISTICS	FREQUENCY (%) (n=21)
Type of Organization	
Health System	50(10)
Medical Center	30(6)
Hospital	20(4)
Organizations' Geographical Distribution	
Atlantic Coast	33(7)
Pacific Coast	24(5)
Mid- and Southwest	43(9)
Organizations' Geographical Coverage	
Urban	55(11)
Urban and Rural	45(9)

Even though not collected over the course of the interviews, additional data are reported in order to present a more complete profile of the participating organizations. The following chart was drawn from indicators provided by the 2013 edition of the American Hospital Association's Guide and shows the number of beds and employees per organization.

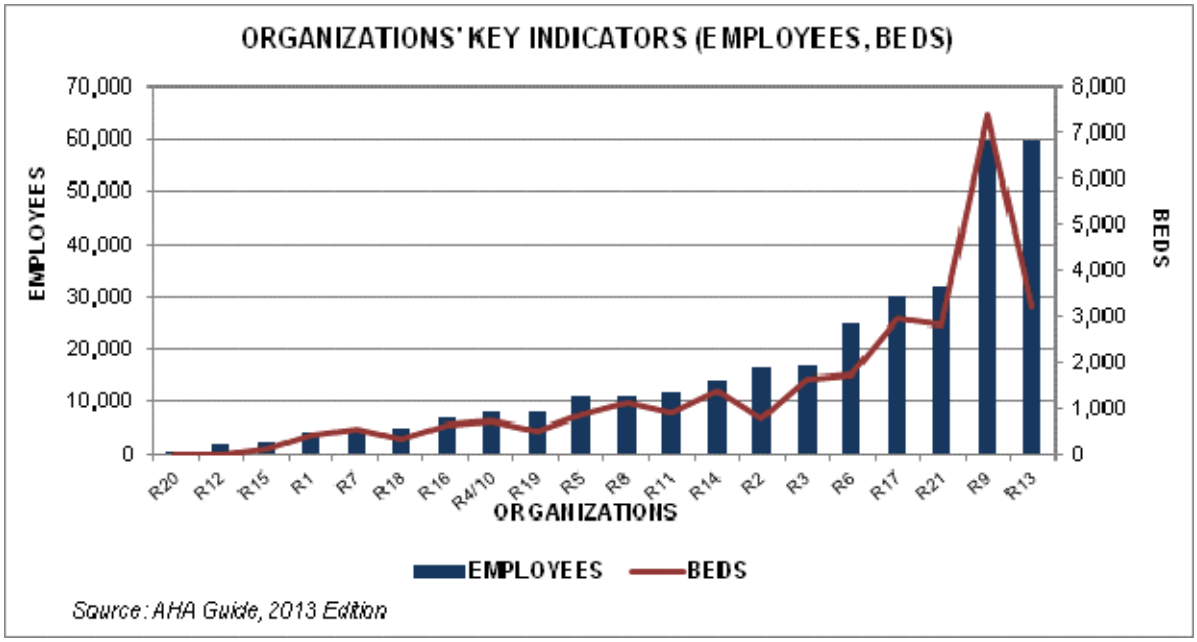

Figure 4 – Organizations' Key Indicators

1.3. Health Data Warehousing Environments

Most systems (81%, n=17) were said to be Enterprise Data Warehouses. However, four respondents (19%) reported the existence in their organization of multiple warehousing systems each addressing the analytics needs of various business areas, i.e. financial, clinical, research and/or education.

While two systems (10%) were purchased as pre-built packages, the overwhelming majority (90%, n=19) were custom-developed, internally designed and built data warehouses. Only four respondents described their design and data model. While one of them used the Inmon 3rd Normal Form, two had adopted the Kimball Star Schema and one described his organization's model as "non-traditional." One respondent labeled the warehousing environment as a "100% self-served model."

In terms of technical components such as database, ETL and BI layer, it was found that a wide array of vendor products were used. One respondent reported using Open Source references to develop some aspects of the warehouse. Table 13 lists the various vendor products by frequency.

Table 13 – Frequency of Vendor Products

VENDOR PRODUCTS	FREQUENCY (%) (n=21)
Microsoft SQL	5(24)
Oracle Database	5(24)
Tableau	4(19)
Cognos	4(19)
Business Object	3(14)
Netezza	3(14)
Sharepoint	2(10)
Microstategy	2(10)
I2B2	2(10)
Informatica	2(10)
Cogito	2(10)
Crystal Reports	1(5)
OBIEE	1(5)
SAS	1(5)
McKesson	1(5)
Netshare	1(5)
Infosphere	1(5)

1.4. Organizational Environments

1.4.1. Business Goals

Unsurprisingly, as stated by the participants, the top three business goals served by the data warehouse were: healthcare reform, clinical research and meeting reporting needs. The signing into law of the American Recovery and Reinvestment Act (also known as the "stimulus bill") in February 2009 initiated a profound reform of the US healthcare system. From the implementation of Electronic Health Records to the development of Health Information Exchanges and Accountable Care Organizations, a paradigm shift

is transforming the US healthcare system from volume- to performance-based. The reform is heavily driven by information technologies, the "meaningful use" of which is linked to financial incentives, be it for the electronic exchange of data or the reporting of clinical quality measures. In order to comply with the new regulations, organizations must "manage their data" and the best available tools to achieve this objective are undoubtedly data warehouses and BI platforms. Respondents clearly stated the implications for their departments of this new regulatory framework:

> With all the changes that are occurring within the healthcare landscape we know that we're going to need to know methods that determine how to deliver care efficiently and as effectively as possible, with all these changes like ACOs, bundled payment initiatives, all sorts of stuff coming down the pike. (R8)
>
> We know that we are under regulations to actually be able to provide assessment for our meaningful use deliveries that we have invested in. That is one of the biggest pieces for us here. (R4)

> To meet the ever expanding quality reporting requirements has become a priority and in order to meet that need effectively we had to stop building an army of data collectors and data reporters. (R1)

As exemplified by the following quotes, the next most often cited business goals were support to the organization's mission, provision of information, patient care improvement as well as operations and financial analysis.

> The data warehouse needs to support our mission of providing high quality care at effective costs, that's to really support the business. It also needs to support the educational and research missions of the institution. (R10)

> We have high level drivers: timely, accurate, accessible, actionable information. (R7)

> Improve patient care and quality outcomes are two important goals. (R16)

1.4.2. Sponsorship

The majority of respondents (81%, n=17) reported widespread sponsorship for the data warehouse with support stemming from the executive level and high visibility throughout the organization. In four instances (19%), sponsorship was deemed insufficient or even lacking. The following reasons were expressed:

> There is some sort of sponsorship. (R11)

> I would say there is widespread interest. Sponsorship is spotty. We have certain leaders that are very much evangelists and supporters, others that are kind of skeptics. So it is a mix. (R7)

> That's actually been a struggle for us. Much of the direction of the warehouse more than I would like has come from IT over the years. That's starting to change. We're trying to develop a more formal data governance structure. (R14)

> There is not. I would say it's growing though. What's been very encouraging this year is that a lot more leaders know about it, know what it is and actually verbally support it. (R18)

1.4.3. Resources

Other than categorizing them as capital expenditures, full-time equivalents (FTEs) and operating budgets, respondents did not offer a detailed account of resources.

No consensus was reached on the number and type of personnel to take into consideration. Some respondents referred to those employees directly reporting to them, with roles related to data acquisition, integration or modeling, and titles such as data architect, database administrator or developer. Others included business and data analysts and even consultants and contractors. As a result, the reported figures ranged from 3.5 to 40 FTEs.

Capital expenditures and operating budgets were neither described nor detailed. Their amount also varied widely with the former ranging from US$100,000 to 400,000 and the latter ranging from US$0.5 to 3.5 million.

An unexpectedly high proportion of respondents (43%, n=9) deemed the level of resources sufficient. Two of them even found it above average and one reported being confident that resources would easily be increased in the near future. As shown by the following quotes, those who found their resources insufficient (57%, n=12), did so as a result of being continuously unable to meet an ever-increasing demand for data.

> I don't think it's a big enough team. It is if they're content with waiting but usually there's just so much work and so many requests that get escalated that in order to do those requests they would have to either add an FTE to my team or they would have to give us some dollars to contract out. We continue to see that both additional analysts and additional developers need to be hired. Also, we can't keep up with all the training needs between the tools and the data training that folks are asking for. (R18)

> Our project list is longer than we can accommodate. (R6)

> As far as our team goes, because there's so much demand for data to be added to the data warehouse for various business and clinical reasons, we always feel like we can use more people, so people have to prioritize what they want based on the current staff level. (R9)

1.4.4. Types and Number of Users

The users of the systems were described based on their business area (operations personnel, clinicians, physicians and research personnel) as well as access to and use of the data, i.e. users with direct access who query the warehouse on behalf of others (power users) and users who only access the data warehouse through the BI layer (secondary users). Respondents were unable to precisely quantify the number of users. When figures were given, these varied between 15 and 280 for power users and from 200 to several thousand for secondary users. The following quotes exemplify the incertitude around the number of users:

> We probably have 2 or 3 dozen power users. (R14)

> We have about 250 users who access the data warehouse directly. (R19)

> For our request community, it's probably close to 200. (R2)

> The reports that are created, consumers of those it's many thousand. (R21)

The inability to quantify the number of users was justified by one of the respondents:

> There are some dashboards and such that are derived of the data in the data warehouse but we don't know how many people are consuming those dashboards. We're working on getting more insight into that. We can audit the different tools to see who's coming into them and we're also working on that but who knows who sends a copy in an email to somebody. It's really hard to tell what the total number is. (R18)

1.4.5. Training, Technical Support and Knowledge Sharing

Training was offered in all participating organizations and included initial training on BI tools and data models as well as ad hoc training on specific tools or areas of analysis. "Train the trainer" was used as a

method in three organizations and relied on highly skilled personnel to train more junior or additional staff in other departments.

Technical support was organized in three different modalities: specialized helpdesk for data warehousing alone (14%, n=3); integration of first-level support into the organization's central helpdesk (24%, n=5); use of the organization's central helpdesk as a ticketing/routing system to the data warehouse team (33%, n=7); and electronic mailbox where ad hoc questions could be sent (14%, n=3).
Knowledge sharing was used in most organizations (71%, n=15) and leveraged user group meetings, listserv, interactive Wiki/Sharepoint repositories, videos and FAQs/documentation materials.

2. Exploratory Findings

2.1. State of Health Data Warehousing Evaluation

As stated above, one of the study's objectives was to utilize exploration research to investigate a topic for which only a handful of publications could be found in the literature and to bridge this knowledge gap by addressing the question "what is the state of health data warehousing evaluation?"

Only one respondent reported evaluating the technology and did so from a return on investment (ROI) perspective, including number of FTEs saved and time saved in data extraction to be made available for performance improvement projects. The respondent also mentioned evaluating the improvement of key primary indicators and data quality.

Moreover, this respondent indicated being accountable for the assessment and for demonstrating financial advantages as well as the delivery of highly accurate data. Similarly, providing cost-benefit analysis was described by another respondent as an explicit role and a responsibility s/he was tasked with.

A major finding of the research is that, not only in practice but also from a theoretical standpoint, the concept of evaluation itself is very seldom considered with regard to health data warehousing. As shown on Figure 5, the representation in a word cloud of the interviews' top 15 words of four letters or more symbolizes this finding. Even though the study focused on evaluation, the word cloud does not include any term pertaining to it.

Figure 5 – Word Cloud of top 15 words

As shown on Figure 6, when added to the list, the interviews' mentions of evaluation, measure, assessment, monitoring, and standard all rank at the bottom. It is noteworthy that there were only two occurrences of the expression "best practice." As shown on Figure 7, the distribution of evaluation terminology confirms this pattern. The respondent who referred the most to evaluation terminology (R12) did so less than 1% of the time.

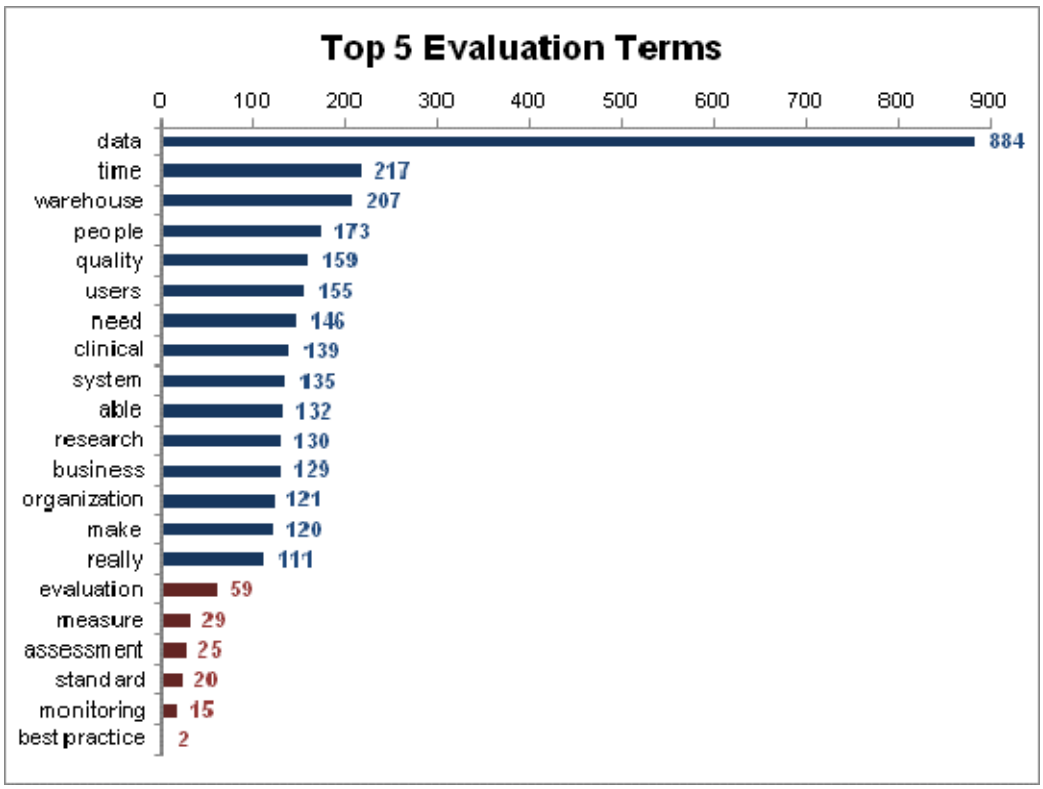

Figure 6 – Top 5 Evaluation Terms

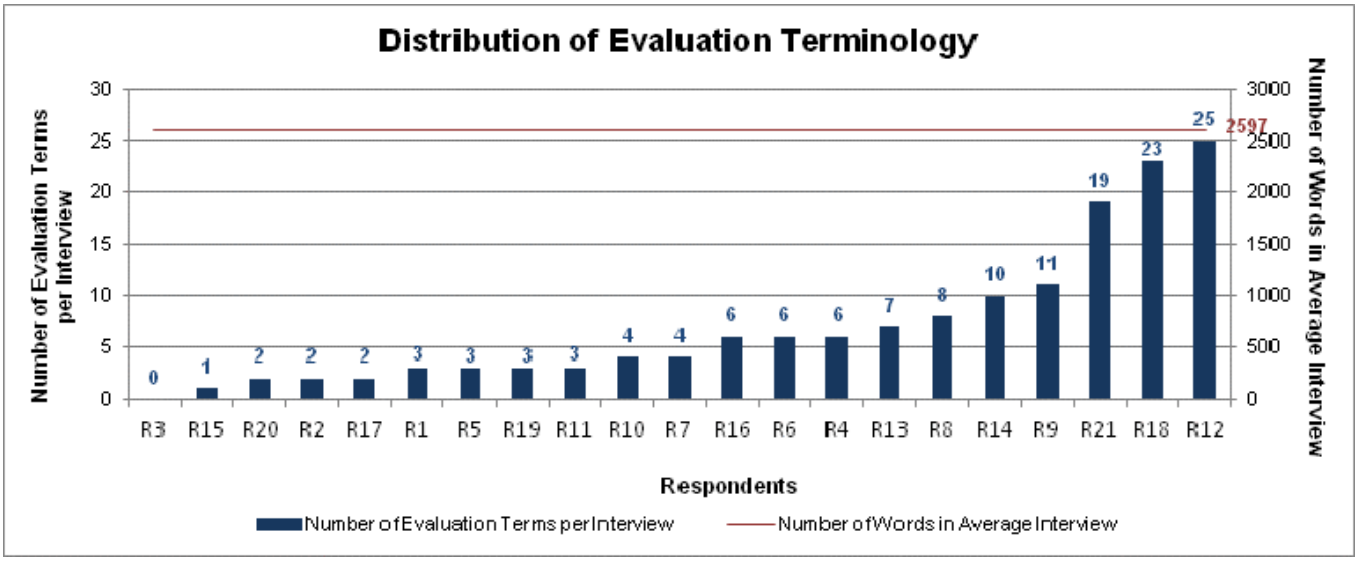

Figure 7 – Distribution of Evaluation Terminology

Evaluation was considered by only 24% of respondents (n=5). It was financial in nature and, rather than involving validated assessment methods, was presented as an informal way to demonstrate the value of

the technology to the organization through results achieved by users within the context of specific initiatives. The following quotes show how informal assessments relied on a project-based approach:

> Our success is tied to many projects that we are key partner and contributor to. More informally, we certainly have over the years and continue to look at the value of the FTEs and capital investment and other investments that we're putting into the EDW and their return for the organization. (R21)
>
> We look at whether the projects that resources are engaged in are of critical value to the company. (R15)

> When we look at whether the data warehouse is a fit for a particular business problem that's being presented to us we talk about measures of the success to make sure that what we're doing and how we're spending our resources and time is contributing to our overall corporate health system-wide goals. (R6)

Overall, the systems were not formally evaluated (76%, n=16). Moreover, evaluation was not perceived as necessary at the organizational level (76%, n=16). As shown by the following quotes, respondents were unequivocal about the absence of formal evaluation:

> We don't do anything scientific to evaluate the data warehouse. (R5)

> It is not evaluated because there is nobody outside of the EDI team that could come up with parameters for evaluation and we have not ourselves established objective and measurable criteria by which we would evaluate the warehouse. (R12)

> It hasn't been formally evaluated and if it were there would probably be a lot of things we want to improve upon. As far as I know, [name of organization] doesn't have any kind of formal evaluation of data warehousing. (R13)

The above-mentioned findings depict the irony and paradox of health data warehousing evaluation – or lack thereof – i.e. the fact that the technology helps promote a data-driven culture based on measures and a single version of the truth, but that very few metrics are used for data warehouses themselves, be it to assess their cost, their performance or the quality of their output. A respondent described the paradox with regard to his/her organization:

> If we ask the business do we have to have this, they would say no, but I would like to be as data-driven in our decisions around investments. I personally feel the need to assess those values and benefits in a more consistent way going forward, especially when I'm asking for new FTEs and dollars. (R21)

The research thus elucidated why health data warehousing evaluation is a topic left unaddressed in the literature. The assessment is not performed nor is it deemed necessary by many organizations. On the other hand, the system's Critical Success Factors (CSFs) are far more exploited by the literature and were logically anticipated to be prevalent in the research as well. Contrary to this assumption, only 30% of respondents addressed the topic and they did so by stating not referring to them. Only one respondent cited a known factor, i.e. sponsorship.

2.2. Use of Data Warehousing to Improve Healthcare Efficiency

The research also intended to explore how data warehousing is used, particularly with regard to improving healthcare efficiency. By accounting for a large array of initiatives, the research confirmed that data warehousing is significantly impacting healthcare efficiency which is improved by addressing waste and processes, and that consequently the technology contributes to reducing costs, as discussed below..

2.2.1. Waste Reduction

Waste is pervasive in healthcare, be it the overuse of procedures not proven useful, the underuse of necessary treatments or the occurrence of errors and defects. Respondents highlighted various forms of waste: excessive use of blood products, excessive use of implants, and unnecessary imaging and laboratory tests. Nearly half of respondents (48%, n=10) provided examples of how the data warehouse

helped successfully remediate these issues. The following quote offers an example of the outcomes obtained as a result of using the data warehouse:

> This year for example we had a goal around reducing blood utilization around the company for surgeries. It's our surgical services for clinical program that oversees that program and we have 2 or 3 team members that have the majority of their time to support that particular project to make sure that physicians were following the guidelines and best practices for appropriate blood use before during and after surgeries. As part of that they had estimates before the project began as to what cost savings they wanted to drive out for blood. It was in the tens of millions of dollars. Because it was established at the beginning of the project we had to say we're going to measure those gains throughout the project. We helped with the business definition around how they wanted to measure and created a dashboard to measure exactly the compliance to that best practice and the kind of cumulative savings were achieved as part of that project. Today we can go to the dashboard and look at that project where we had saved the organization tens of millions of dollars. To the point where, in a discussion yesterday with one of our surgical services leaders, he said that the Red Cross is actually re-forecasting the need for blood next year in the state of [name of the State] because there is no longer a shortage of blood because we're utilizing less by appropriately managing how blood is given and used. It's the whole supply chain of blood that is seeing the results of our efforts. (R21)

2.2.2. Process Improvement

Like any other industry, healthcare relies on processes to add value. However, the processes found in healthcare are far more complex than those in sectors such as the manufacturing industry. Not only do they involve interdisciplinary interventions, they largely depend on information and knowledge. What healthcare also has in common with other industries is an abundance of quality issues. These are the

results of variations in care processes and in turn lead to outcome variations, i.e. inefficiencies. Improving processes is thus essential to bring greater efficiency to healthcare and data warehouses are instrumental in enabling such improvements.

Most respondents (71%, n=15) offered examples of the use of the technology to improve processes. Patient throughput, laboratory throughput, occupancy rates and hospital acquired conditions were most often cited as areas in which the data warehouse had contributed to increased efficiency. The following quotes exemplify the results achieved in the area of process improvement:

> There's been a project with ED metrics so they can track how well they're doing in each of these areas with the patient throughput and the patient care and if they saw somewhere where the time between point A and point B was taking too long they could evaluate and determine what changes they needed to make. (R9)

> Lab throughput time, understanding from the time the lab was ordered, the time the blood was drawn, the lab hit the lab instrument, the time that the lab result was available, the time that the lab tech verified it and the time that it went back to the EMR, so process improvement from a time stamping from each of the different steps in the process. (R1)

> Our occupancy dashboard is another example. There are actually a number of patients utilizing beds because they're waiting for long-term care. Now these numbers are known so the problem can be dealt with directly. (R11)

> We also monitor hospital acquired conditions, so just preventing unintended harm by highlighting where it is happening and then using process improvement to go fix that which in itself reduces costs and even increases revenue because quite often hospitals are not reimbursed for hospital acquired conditions. (R9)

2.2.3. Cost Reduction

From supply cost optimization to physician productivity tracking, pharmaceuticals consumption and cost analyses of readmission rates and lengths of stay, most respondents (95%, n=20) indicated how data warehousing is used in financial and operational areas. In each of these instances the technology facilitated financial and performance analyses to assess and increase effectiveness and productivity. The following quotes offer examples of the cost reductions achieved as a result of using the data warehouse:

> We did a supply chain project. We initially had a warehouse full of goods, we used to keep a large inventory. We worked with the folks who tried to implement a new supply chain process. They were able to use a program similar to what people do at Toyota in Japan and were able to reduce the supply to the point where we no longer needed such a big warehouse. Objects were ordered just in time. Where we're going is that we're tying with the ER and OR data with scheduled surgeries and we've figured the schedule that their supply rotates through and we keep track of consumption. So we can improve the process even further by anticipating future needs. (R18)

> We look at pharmaceuticals ordered. For specific diseases, conditions, against the demographics, against medications prescribed, especially with antibiotics (out of 2, 1 can be very expensive, 1 can be fairly inexpensive but from an efficacy perspective it can do what the other does, so we do a lot of work in that regard as well). (R1)

2.3. Use of Data Warehousing for Medical, Clinical and Research Purposes

Data warehousing is also used for clinical and medical purposes. Automation such as that provided by Electronic Health Records (EHRs) is not sufficient to improve clinical practice as a whole. The latter only occurs once data is aggregated and converted into multidimensional information which can then be used

to measure and improve processes with direct impact on patient care. Over half of respondents (52%, n=11) offered ample applications of the use of the technology in medical and clinical areas.

Data warehousing is also used for research purposes. By enabling the comparison and contrast of causes, symptoms and treatments, data warehouses make it possible to determine a course of action to address illnesses. Moreover, by providing continuously updated repositories along with an inherent time dimension, data warehousing enables population analyses in both a retrospective and forward-looking fashion. From outcome research to cohort discovery and the identification of potential cohorts for clinical trials, the majority of respondents (81%, n=17) offered various accounts of such utilization. Additionally, those affiliated with teaching institutions reported using the system to support the research requirements of their residents.

The following quotes offer examples of accomplishments in the above-mentioned areas:

> Another example of what we will do, it's a project that tracks vaccine administration for hospital patients, this is again a regulatory component of a core measure, in addition to the manual validation as we were developing that work we sent out reports that not only showed graphically the percent of adherence with vaccine protocols but we also sent a report that showed the failures so there was a line item by line item account of those patients whose care was not in compliance with the protocol. (R14)

> We've done over 100 requests over the last year which is pretty much direct support to research either retrospective research or prospective identifying cohorts to use in clinical trials. It supports retrospective outcomes research and other retrospective care analysis. (R10)

> We've also married the clinical data with billing data to assist in terms of outcome research and effectiveness research. For example, when we do this treatment vs. that treatment one has a longer length of stay and a higher cost. Do we see that it results in a greater survival curve? The interesting thing is the breadth of the research we're able to do in terms of being more translational or being able to look at finance and clinical evaluation. (R15)

2.4. Raison d'Etre of Health Data Warehousing

The areas designated as business goals were also those for which data warehousing brought the most significant results, i.e. healthcare reform, clinical use, quality improvement and research. Areas such as nursing or finance were said to yield less impactful results either because the projects had not yet reached the same level of maturity or because of a lack of resources and/or data-driven culture in the concerned units.

An unexpectedly high proportion of respondents (38%, n=8) found it possible to obtain similar results without a data warehouse. However, identical results were usually deemed unattainable without using the system (57%, n=12). In two instances, the system was deemed justified for cultural and/or organizational reasons:

> Without such a focus on data and information-based decision making we would not be where we are today. (R21)

> I don't know that people would know what to do in [name of organization] without having the data warehouse available. (R6)

One respondent demonstrated how, in some instances, the use of the system may not be warranted:

> There are times when we say these are not things that the warehouse will do because there are other ways that we know it can be done and probably better.

> Sometimes with maturity things are seen as if there's only one way to solve a problem. If you follow that approach it may not be the most effective way. Sometimes you have to know where to follow the scores in music and sometimes you have to know when to improvise. There's a time for both. I think it's a good analogy, sometimes you can be focused on trying to follow the methodology rather than solving the problem and what is the most appropriate way considering the context. We have a somewhat evolved process for extracting data from the source systems and maintaining history and doing the integration of the business rules. Sometimes you can bypass the history. Someone will say I'm doing something preparatory to research and only need this for one time and then we will say there's really no reason for us to put an automated process to source this data. We only need a snapshot of it in order to accomplish this goal. (R15)

The added value of health data warehousing was said to lie in the ease of manipulating data, the speed of delivery and the possibility of unveiling issues which otherwise would have been left unaddressed (86%, n=18). The following quotes clearly demonstrate this added value:

> If you only need data from a single system the data warehouse doesn't add value, but if you need data from different systems then we're the only option. (R2)

> We've been able to give people data that they've never seen before. When that happens they can make decisions better than before. For example we've been able to affect treatment for patient, patient safety, we're perfecting better patient outcomes, reducing risk, all kinds of things. We've answered more of the simpler questions by getting canned and parameterized reports and dashboards distributed. The thing is that it leads to more questions being asked and now we get just as many requests as we used to before the self-service reports. These new

> questions are harder and linked to the fact that people have discovered things they had never seen before and were able to make decisions based on that. (R18)

As clearly indicated by one of the respondents, data integration is central to health data warehousing's raison d'être:

> Like many organizations we've selected systems by taking a best of bread approach, so we have hundreds of different clinical and operational systems, data flows through them, to some extent some more than others. The data warehouse has been able to fill that gap of a holistic view and be the place where disparate systems are tied together to get a more complete picture. A patient is a patient system-wide with every facet of the organization he/she interacts with and we should be able to organize our information from that viewpoint. The data warehouse is what enables to deliver that capability. (R8)

Moreover, the raison d'être extends far beyond feasibility and increased data accuracy to encompass benefits at the organizational level as well as for healthcare as a whole:

> The idea of the data warehouse is that it creates communication and consistency among departments. Each department could go on and continue to get what they need on their own but I think there is a greater sense of consistency and communication across the organization by having the data unified. Because of that, having a project focused around data drives our ability to enforce quality and ultimately that reflects in the care we provide and in our ability to perform education and research. (R10)

3. Current Evaluation Practices

Another objective of the empirical study was to address how health data warehousing evaluation should be conducted and to enable a comparison of the framework previously developed with current practices. A series of seven factors were studied.

3.1. User Needs Assessments

Nearly a quarter of respondents (24%, n=5) stated their organization did not perform any user needs assessment prior to the development of the data warehouse. Out of those who did (67%, n=14), only three reported having formal follow-up mechanisms in place.

The occurrence of post-implementation assessments was below 50% and a third of those were performed on a project or subject matter basis (13%, n=3).

A very low number - 50% - of the initial needs assessments had been met and only 44% of post-implementation assessments had been addressed.

3.2. Costs Evaluation

In most cases (71%, n=15), the cost of the technology was not formally evaluated. When an initial assessment was performed it was partially conducted (19%, n=4) and in only a few instances was cost evaluation considered in the future (10%, n=2).

While one respondent reported an attempt at establishing a chargeback system, another two described ROI in the following manner:

> ROI is the ease by which we can get data today. Requests that would take weeks to sort out now take a few hours to do. (R20)

> I have to show ROI based on usage as well as the ability to reduce disparate data stores, data islands or additional data tools that we purchased because we don't have the data integrated. (R3)

Even though no formal cost-benefit or ROI evaluation was performed by one respondent, s/he offered a detailed account of budgeting processes which involved the use of the data warehouse itself to assess expenses:

> We have our annual budget that is part of our annual IT budget that we plan on our overall expenses (new tools or software, upgrades that need to happen). The biggest expense is FTEs. We have a time tracking system and tool so we know how the hours are spent and by business unit we're able to say how much EDW resources from an FTE perspective was spent either supporting existing tools and data sources and datasets or was working on new development and projects and that can all be broken out by using the EDW because we have that data and use our tools to be able to tell the business how much resources are being put into various areas of the organization. They see more of the FTE expense which is most of the expense. The rest of it is behind the scene and is part of overall cost and chargeback for IS services. (R21)

In three instances, the assessment was described as project-based:

> Occasionally an individual project might be submitted with a bit of an ROI and we'll obviously take that into consideration. (R11)

> We would do occasionally that kind of analyses in order to determine what the scope of a project is. (R9)

> The way we measure expense on FTEs perspective is on a project by project basis. (R21)

3.3. Benefits Evaluation

While the benefits of health data warehousing were not formally evaluated, an outcome assessment of the individual projects supported by the technology was performed nearly one time out of three (29%, n=6). Respondents explained such assessment in the following terms:

> Those individual projects are tracked and outcomes are identified but we don't really collect those in an overall assessment of the value that the warehouse provides. (R14)

> Since each of these initiatives have been customer-driven we have from time to time associated the value derived from delivering a particular piece of the warehouse but we haven't done anything to roll up the entire system. (R15)

> The only evaluation we do is post-project. We go through an exercise to evaluate if the project met the requirements. (R19)

3.4. Data Quality Evaluation

Data quality was essentially considered in terms of reliability, i.e. the concordance with the source systems. Rather than being evaluated per se, it was either monitored through the automated validations provided by ETL processes (38%, n=8) or it consisted of record counts and manual processes to match and compare content between source systems and the data warehouse (33%, n=7). The availability and completeness of the data were also considered facets of data quality and were monitored by 19% of respondents (n=4).

Discrepancies between the source systems and the data warehouse were unanimously acknowledged. The quality of the data was equally seen as dependent upon that of the source systems, and corrections

of identified variations were commonly handled upstream rather than at the warehouse level. The following quote summarizes the data quality assessments:

> Our philosophy on data quality is that the EDW's quality is measured in how closely it matches the source systems. If we match the source system 100% of the time then the EDW has 100% accuracy. If there are errors or bugs that produce odd data that is outside of the EDW data quality. We don't do any data correction upfront. (R6)

The absence of formal data quality evaluation was reported in three instances (14%). Moreover, in those cases the assessment was left to the appreciation of users:

> There is no formal evaluation of the data. We are leaving that up to the care process teams to make sure that the data is meaningful to them, that it gives them the information they are looking for. Is it accurate, does it reflect what is going on in the process work that they're working on? We ask them to make sure the data is good, clean and meaningful. (R16)

The relevance of the data, on the other hand, was never cited as being formally evaluated. However, the purpose of the assessment was described by a respondent in the following terms:

> Is the data in the data warehouse the data that everyone is looking for? (R1)

If reference was made to metadata, data dictionaries and even metareports (19%, n=4), these cannot be considered as assessment methods but are rather ways to document data quality. The use of metareport was described by a respondent as follow:

> Metareport which is data about a report that documents who the author is, the reason the report was created, who the audience is. For data quality it's then, the developer can document the query that was used, the metrics that was used, how it was calculated. (R21)

Similarly, data governance and stewardship were presented as ways to evaluate data quality (33%, n=7), though they are, in fact, means to establish, validate, and enforce data management policies and strategies.

3.5. Technical Effectiveness Evaluation

Rather than being evaluated, the effectiveness of the data warehouse was monitored through a series of system-generated metrics which encompassed query response time and quality, CPU usage and system uptime (62%, n=13). Neither scalability nor flexibility was evaluated. However, one respondent acknowledged the lingering utilization of MS Excel and Access for analytics purposes in some areas of the organization while another cited the limited capability of the system to handle external sources.

3.6. Early and Ongoing Generation of Value

The concept of early and ongoing generation of value is a CSF often cited in the literature. If two respondents (10%) acknowledged having adopted the opposite scenario, i.e. “build and they will come,” an overwhelming majority (90%, n=19) adhered to the concept. The latter is part of a dynamic that characterizes data warehousing and was described by a respondent in the following terms:

> Once people start using it the needs arise, so we’re continually providing more and more functionalities. (R1)

Such value was generated through time-bound delivery and the use of prototypes, by prioritizing use cases as well as enabling immediate use and collaborative work on a project basis. The following respondents offered an explanation of such time-bound delivery:

> We begin to get that sort of timeframe of 6 to 8 weeks for some of our deliverables and tighten it up a little bit over time as we get more and more experienced with that. We’re rolling more and more of the model and the different components over time but structured in a way that we can have a very repeatable cycle within that. (R8)

> We show prototypes within the first 2 to 3 weeks. We build reports of off prototype data. You haven't even started the ETL but we also build the semantic layer to allow them to run reports. In the meantime the users are working on their prototype table that will ultimately become the finalized table. They have access to the data long before the data mart has been finalized. (R19)

> We always look at the use cases when people ask for something that's not there yet. We know there's still a lot that is not in there but because we have to so carefully prioritize we want to make sure we're not just adding something on a whim. We try to get use cases ahead of time and make sure they're met after we deliver. (R18)

To assess the delivery of value, respondents recommended assessing the amount of active time spent by developers on the system; the time spent on dashboards; the number of reports accessed; and the number of dashboards and reports built.

3.7. Usage Evaluation

From logins to the number of queries run as well as the type and number of reports and dashboards accessed, all systems offered the capability to track usage in an automated fashion. However, rather than being formally evaluated, utilization was monitored with various degrees of regularity and as noted in Section 1.4.4., respondents did not provide a specific account of the number of users. The following quote explains how such evaluation is automatically generated by the system:

> I don't have to spend a lot of time generating that data, it gets captured by the vendor tools, a lot of it is just presentation. All that data is online. We keep track of how many queries and for what purpose. We do check it from time to time, to say how many queries get run. (R15)

Similarly, only three respondents (14%) conducted surveys to assess user satisfaction. In all other instances, user satisfaction was not formally assessed. Issues were communicated using the same channels described for technical support and knowledge sharing in Section 1.4.5., i.e. ticketing system, helpdesk, users group meetings, electronic mailbox and direct contact by phone.

Some respondents described users' issues very candidly:

> We don't have any formal process like a 6-month forum to review processes with these people so we tend not get feedback. It would be nice to do something more formal. We actually have a fair number of issues, we have things like error messages and people don't get their report. We keep tabs on how often that happens and try to work with the vendor to resolve anything that might be an issue. (R15)

> I hear complaints when they are directly sent to me or through the grapevine. The main complaint here is that people don't know how to get to the data and if you don't have an analyst who works directly with us it can be a challenge. (R19)

> More than I like there are problems I hear about from the Vice-Chancellor telling me that researchers are unhappy. (R10)

> I found out in a few instances that people were not using certain applications much anymore, but we don't really follow up. (R17)

3.8. Evaluation Components and Factors

Nearly all respondents (90%, n=19) provided feedback on what the evaluation should entail. They cited 29 components for which they determined a total of 94 factors. Table 14 ranks the list of components and

factors proposed by the participants by frequency of citation along with the respondents who mentioned them.

Table 14 – Evaluation Components and Factors

EVALUATION COMPONENTS	EVALUATION FACTORS	RESPONDENTS
Benefits	Achieved outcomes Grants/funding leveraged (in)Tangibles from a customer perspective Business value Ability to look at data in near real time Improved turnaround time for data acquisition Number of requests addressed Number of dashboards produced Number of users	R10, R11, R15, R17, R18
Costs	Manpower Capital Maintenance (infrastructure) expenses Enhancement (infrastructure) expenses Project-based costing Publication/dissemination of costs	R5, R10, R11, R18
Support to Mission	Data provided for secondary use Support to research mission Support to educational mission Link to corporate goals	R9, R10, R14, R15
Impact on Patient Care	Patient care improvement Patient care delivery improvement Outcomes improvement Patient satisfaction improvement Patient safety improvement	R10, R14, R16, R18
Things Impossible to Do Before	Questions previously unaddressed Impact of complete and integrated data Improved decision making	R5, R13, R15, R18
Physical Infrastructure	CPU usage Memory capacity ETL tools Reporting tools Data quality tools Master data management tools Applications software Tools streamlining	R3, R9, R19, R21
Financial Impact	Savings Costs reduction Organization-wide efficiencies ROI Value of data as an asset Increased market share	R7, R10, R14
Source Systems	Data feeds confidence level Data integration Data completeness	R1, R13, R21
Utilization	Number of users Number of queries run Number of ad hoc analyses Dashboards traffic	R10, R11

Table 14 – Evaluation Components and Factors (continued)

EVALUATION COMPONENTS	EVALUATION FACTORS	RESPONDENTS
Utilization	Number of users Number of queries run Number of ad hoc analyses Dashboards traffic	R10, R11
Users' Needs	Data relevance Alignment of system to users' needs User needs which have been addressed Known user needs yet to be addressed Anticipated user needs	R1, R10
User Satisfaction	Results quantification Degree of satisfaction Satisfaction with tools content Satisfaction with tools stability	R6, R15
Compliance with Regulations	Ability to respond quickly to regulatory requirements	R14, R21
Security	Access to data Data encryption Firewalls Offline data Response to security breach	R4, R21
Customer Commitment	Business backing (time, effort)	R9, R17
Sponsorship	Strength of sponsorship	R9, R21
HR MAnagement	Skill set Leadership	R9, R21
System Performance	Delivery speed Defect rate System responsiveness	R5, R19
Care Continuum	Data integration across care continuum Ability to provide holistic view of patients across care continuum	R5, R13
Data Harmonization	Ontological harmonization	R1
Training	Data warehousing team Users	R14
Governance	Projects review processes Projects prioritization processes Project approval processes Data quality processes	R21
Adoption Rate	Number of users How the system is used How the system supports decision making	R8
Users Cohesion	At the organization level At the project level	R 10 R2
System Flexibility	Ability to handle future data needs Ability to adjust to changing healthcare environment	
Staff Service	Performance of data warehousing team Ability of data warehousing to meet business requirements	R21

Table 14 – Evaluation Components and Factors (continued)

EVALUATION COMPONENTS	EVALUATION FACTORS	RESPONDENTS
Single Source of Truth	Solutions harmonization/centralization	R3
Data Accuracy	Provider master data Patient master data Location master data	R13
Data Quality		R7
Data Latency	Data time stamp Time range	R7

3.9. Evaluation Methods

Eighty-four per cent (n=16) of those who provided feedback on evaluation components and factors also recommended methods to evaluate the data warehouse. A series of 14 methods and 45 evaluation items were determined. Table 15 ranks the methods by frequency along with the items they intend to measure and the respondents who mentioned them.

4. Explanatory Findings

Beyond the exploration of health data warehousing and current evaluation practices, the semi-structured interviews added an explanatory value to the research. Through further analysis of the content, it was possible to determine why the evaluation was not performed, what took place in lieu of evaluation and whether alternatives were considered for the future.

4.1. Anecdotal Evidence

Often, respondents did not address the questions asked by the researcher, due in part to the fact that they were not formally evaluating the system and thus not familiar with the topic, but more importantly, because they could not relate to the concept itself. When asked how they would assess an aspect of the warehouse, some respondents would describe the aspect at stake instead of the ways in which it was or could be assessed. When asked how to evaluate benefits, some respondents would describe the benefits of using the data warehouse. When asked how to assess the types of users, some respondents would describe who the users were. When asked how to evaluate the flexibility of the system, some

Table 15 – Evaluation Methods

EVALUATION METHODS	EVALUATION ITEMS	RESPONDENTS
Users Surveys	How data was used When data was used Where users were Complexity of missing data Performance time How available tools meet users expectations Perception of the data warehouse Experience with the data warehouse Integration of use in users workflow Utilization impact/results	R3, R5, R6, R7, R8, R10, R13, R14, R19, R21
System Monitoring	Database tracking Dashboards tracking Speed of delivery Amount of EMR data available in the data warehouse Performance of analytic queries Who run queries Type of data queried System stability System uptime ETL processes Data streams anomalies Reports/dashboards content consolidation with source systems	R6, R7, R11, R14, R18
Usage Tracking	Distinct tools users Number of reports Frequency of reports access	R9, R13, R21
Impact Description	Purpose of use Impact on decision making Impact on patient care Impact on patient care delivery Changes brought to as a result of using the data	R11, R16
Multiple Methods	Technical data collection combined with interviews	R8, R13
Cost-benefit Analysis	Benefit of shift from manual to automated analytics Benefit to all departments Increased care quality Costs reduction Improved research outcomes	R9, R11
Informal Meetings	(no item specified)	R2, R21
One-to-One Record Matching	Records consolidation with source systems	R1
Leadership Surveys	(no item specified)	R19
ROI	Quantification of shift from manual to automated analytics by type of personnel and projection at the organization accordingly	R7
Benchmarking	With other healthcare organizations	R7
Focus Groups	How available tools meet expectations	R6
Interviews	Perception of the data warehouse Awareness of the data warehouse Utilization impact/results	R7
Correlation	Of patient care with costs & patient satisfaction	R18

respondents would indicate whether they found it flexible. When asked whether the system was evaluated, some respondents would report the existence of a steering or governance committee overseeing the technology. When asked how to evaluate data integration, some respondents would describe the level of integration of the data.

The inability of respondents to provide precise measures was also very indicative of the lack of formal evaluation.

Unknown number of users. Respondents would mention that the number of users had increased significantly but could not give any specific measure of the increase. Even more so, some of them clearly stated not knowing how many users there were:

> I don't know how many have access at this time. (R16)

> We don't know how many people are consuming these dashboards. (R18)

Unknown FTE count. As stated above (section 1.4.3.), the number of FTEs and the composition of the data warehouse team were vaguely described or left undetermined:

> I have a small team and we have reporting folks and business partners. (R3)

> This is a question I've been asking a lot of people myself. (R10)

> I don't know the FTE count. (R9)

Unknown time saved. One of the cited benefits of data warehousing is the time saved in data acquisition and transformation. However, the amount of time saved was typically unknown:

> I don't know what the hours are, we freed up a lot of time. (R1)

> People may say it's saving us so much time but in reality is it helping a lot? We're not really sure. (R17)

Unknown capital expenditures. Budgets were also often undetermined:

> I don't know what the dollar numbers are. (R6)

> It's hard to say what the annual cost is. (R18)

Overall, whenever an assessment was made, it relied on anecdotal evidence and respondents would qualify it as such:

> Because of how the work had historically been performed it's been very anecdotal. (R8)

> We do look for the early achievements but we don't evaluate, it's anecdotal. (R5)

> The effectiveness of the architecture, it`s hard to know other than anecdotally. (R12)

> For users' assessments, it's more anecdotal and ad hoc gathering of information on particular issues. (R13)

> Depending on what the data warehouse has done for different groups in the organization they would probably evaluate us but there is no specific measures they evaluate us with. So we're thinking, the projects we've done before they were happy with us and they liked us but maybe others felt like we were not filling their needs. (R17)

4.2. Explicit Reasons for the Absence of Evaluation

Several respondents offered insight into the lack of evaluation (19%, n=4). On one hand they expressed the absence of explicit request in the organization:

> I would say that it hasn't been brought up" (R11)

On the other hand, they viewed the existence of complaints or concerns as a prerequisite for evaluation:

> There hasn't been any concern or complaint from users. Failure rate has been captured within the support/developer team but we're not publishing that. We know what it is but there hasn't been any concern with it. (R7)

When they addressed the financial evaluation of the system, nearly half of the respondents acknowledged experiencing difficulty in performing the assessment (48%, n=10). One respondent attributed the difficulty to the complexity of allocating costs and benefits:

> I think where it becomes really difficult is that data in and of itself can't provide a changeable cost-benefit, you also need all of the nursing and clinical staff to use that data appropriately and you need to have the support of a clinical area that's going to be following up with the patient that has been discharged and make sure they're taking their medication and have their primary care visit scheduled. Once you get that dollar savings associated with reducing readmission it's hard to allocate that to what portion is the DW and the data that we provide. (R6)

The lack of theoretical knowledge and/or know-how was also cited by a few respondents as a reason for not conducting the assessment, particularly where evaluation methods were concerned (14%, n=3):

> I actually have no idea how to do it. (R19)

> I don't know, I'm not aware of anyone using a method for evaluating the data warehouse. (R3)

> I'm not sure what I would look at. (R6)

As stated above (Section 2.1.), evaluating the system was not perceived as necessary in most organizations. In their comments, three respondents associated this perception with managerial reasons. In one organization, data warehousing was considered indispensable and a necessary expense. This in turn was used to justify the lack of evaluation:

> We don't evaluate the data warehouse. It's basically considered a cost of doing business. (R15)

For one respondent, conducting a financial evaluation was conditioned by the ease of performing the assessment:

> If it's easy to do, then let's figure out better ways to show costs and benefits. (R21)

When assessing data quality, another respondent interrelated evaluation with preventing problems:

> Another way you're really able to ward off problems is to have a governance structure to handle quality. (R1).

4.3. Implicit Reasons for the Absence of Evaluation

Further analysis of the content revealed the existence of two additional factors with potential impact on the system's evaluation. These factors were not explicitly associated with the absence of assessment but were recurrent themes in all interviews.

4.3.1. Evolving Nature of Health Data Warehousing

Health data warehouses are in a constant state of flux, to the extent that it is a known CSF. Not only are the technological components constantly evolving, but the system is affected by organizational as well as medical and regulatory changes. This "evolving nature" was defined as follow:

> The problem with warehousing is that it keeps growing, like layers of paint it never stops getting bigger and the measure needs to see today how efficient are you at delivering what is providing value because the rest of that is at risk of being data warehousing for the sake of doing it not for the sake of the business. (R12)

> We will also occasionally publish the number of queries against the DW by month to reinforce the fact that it's a living and breathing application and it's embedded deeply in a lot of processes throughout the organization. (R14)

> The problem is when you have a DW program you want to continually invest in it. You'll get out of it what you put into it. If you don't keep investing and keep up with the newest technology, you're not going to keep addressing the latest needs like big data or unstructured data. (R18)

Numerous organizational changes were reported and ranged from changes in data analytics strategies and the deployment of data warehousing resources to major investments and the hiring of data warehousing personnel (57%, n=12).

With regard to the development life cycle, over half of the respondents mentioned that the data warehouse was either in an early stage of development, going through a re-design phase or experiencing significant growth (52%, n=11). More importantly, they indicated how ongoing technological advances impacted the system's infrastructure. Furthermore, an increasing number of data sources had to be integrated in order to meet reporting and regulatory requirements or to accommodate users' requests.

One would assume that an unstable environment and changes of such magnitude and frequency would increase the need for evaluation. Not only is this need unrecognized, its lack reinforces the above-noted irony and paradox of health data warehousing evaluation. The evolving nature of health data warehousing was invoked by respondents in the following terms:

> They are recruiting an Executive Director for the EDW and once that person is in place we'll probably consolidate a lot of that into a data management organization. (R10)

We are shifting from a departmental view of data warehousing to an organizational view. (R12)

We're looking at a strategic investment that will nearly double the investment in both capital and operational over the next 3 years. So we're in the process to ramp up investment as well as hire additional staff and engage some contract and consulting resources. (R7)

Some of the support under the new organizational model is still to be worked out. (R9)

We're in the process of re-evaluating that basic strategic design to incorporate some data marts that focus on a smaller set of analytic question. (R14)

It's a constant fight of show and tell and improvements. The data warehouse is not fully developed, it is about 80% developed. (R20)

We're at a transition point with our data warehousing. (R8)

We use 2 tools although one is on its way out to build displays or visualization. We also still have a few legacy components. Some of those are still running but we're not actively developing on that platform anymore and so once we migrate everything off we will not replace them. (R11)

Looking into the future as things continue to grow so rapidly and we get into big data, unstructured data, we're definitely going to have to increase our capacity by buying a bigger appliance. (R18)

> We've acquired an industry-specific data model and we are now working with a data warehouse appliance from IBM (the Netezza product) to host our repository and we've also switched our data integration and BI tools. (R8)

> As we use the data and as the data grows we have to re-factor tables or even modify the architecture. (R2)

4.3.2. Hiring of Consulting Firms

The hiring of external vendors and consultants is common practice for IT departments. The former provide hardware and software solutions along with the necessary maintenance services while the latter are hired for short- or long-term assignments to supplement the existing workforce. Even though it may seem counterproductive to leave to a third party the critical task of evaluating one's needs, it appeared that consultants had been hired in some instances to perform assessment-related tasks.

Initial user needs assessments. Consulting firms conducted needs analyses and users requirements prior to the development of the data warehouse (19%, n=4).

Design and development. Consulting firms assisted in developing the system by assessing strategies, methodologies and data structures (24%, n=5).

Ongoing agreement. A consulting firm was hired on a long-term basis to provide the ongoing monitoring of the data warehouse (5%, n=1)

The following quotes exemplify the hiring of consulting firms:

> So we brought in a consulting partner at the time to help us with a roadmap engagement. They worked with us to come up with a new strategy to meet our future needs and where we're anticipating them going. (R8)

> We actually engaged an outside consultant to help us with the user requirements needs prior to embarking on this project. (R1)

> We had almost a two-year period of needs analysis and we hired an outside consultant who wrote out a number of documents for us before we started developing the data warehouse. (R20)

> We have a monthly contract with a consulting firm and they run a dashboard for us to make sure that our system is healthy. (R2)

4.4. What Was Done Instead

4.4.1. Monitoring Success vs. Evaluating

Rather than evaluating per se, most organizations were monitoring some aspects of the data warehouse by capturing system-generated metrics:

> We have audit trails, we know who queries what part of the data, but that is monitoring of the DW, well I guess you could call it evaluation I suppose, but that is how you monitor what your success is. (R20)

Furthermore, the purpose of such monitoring was to demonstrate the success of the system, mainly by showing the success of business projects as a result of using the technology. However, success itself was not defined and its demonstration did not involve any specific parameter or criterion. The following quotes clearly indicate the intention to demonstrate success:

> Our success on the architecture front is measured by the ability of our current design approaches to meet the needs that are brought to our team by the new projects and our speed in adjusting those patterns to new problems. (R6)

> You don't so much demonstrate the value of the data warehouse in a vacuum, what you need to demonstrate is the success or failure of particular initiatives on a smaller scale. They succeed or fail in part based on the ease and completeness of the access to the data needed to support them. (R14)

> A success factor in the measurement of the effectiveness of the data warehouse is the ability in the end for those quality improvement projects to be successful. So even if it's not a formal evaluation of the EDW, it is the reason why [name of organization] continues to invest in those efforts, it's because we produce as members of the improvement teams and as the infrastructure, we provide the data which is critical to the success of these projects, we're recognized as part of that success. I can probably in any given year be able to tell 10 or 15 of that kind of stories with high-level goal projects where the data warehouse is critical to the success of these projects. (R21)

4.4.2. Assessing Recognition vs. Evaluating

Instead of evaluating the system's components and factors, respondents assessed its recognition. The existence of the data warehouse and the acknowledgement of its importance were assessment criteria in and of themselves. Moreover, recognition alone proved sufficient and precluded a formal evaluation. The following quotes clearly indicate how assessing recognition is considered in lieu of evaluation:

> It really creates a culture where we say and act as if we recognize that the data that we're collecting is an important asset both for patient care and for research and that by having a data warehouse it's something that is recognized as an important outcome of what we do. (R14)

> Somewhere somehow everybody understands the value of the data warehouse, the benefits I couldn't list them all but there is acceptance and desire to pursue the data warehouse initiative. (R11)

The value is universally recognized but not evaluated. When we produce a clinical report that allows the providers to identify and intervene with key patient groups to achieve a specific end, that is recognized as highly valuable delivering on our mission and key to the strategy of the organization. (R12)

We get a pat on the back for doing it but we don't measure that as such. (R5)

The data warehouse has been able to fill that gap of a holistic view and be the place where disparate systems are tied together to get a more complete picture and without the warehouse we would not have that capability. The investment we're making is a real recognition of that. A patient is a patient system-wide with every facet of the organization he/she interacts with and we should be able to organize our information from that viewpoint. The recognition is that the data warehouse is what enables to deliver that capability. (R8)

4.4.3. Perceived Value vs. Evaluation Results

Like recognition, value was often considered an evaluation criterion and involved the perceived value of either the data warehouse itself or the data and information that were made available. Like recognition, the concept of value was neither defined nor converted into precise metrics. However, the mere perception of value was cited as a basis for investment decisions. Perceived value was expressed by respondents in the following terms:

All the projects see a lot of value in having good data. (R11)

Having so many systems to integrate together, it didn't take long before the value was clear and it grew from there. (R2)

We've managed to get the investments we needed mostly based on the perceived value. (R5)

It's not a scientific method, it's user feedback and leadership feedback of the perception of value. (R7)

4.5. Opportunities for Improvement and Assessments Considered for the Future

Over the course of the interviews several respondents highlighted areas in which they believed improvement was needed (43%, n=9). Some areas were related to the evaluation of the system while others pertained to data warehousing management. More importantly, the same respondents considered developing the assessments and addressing the needed improvements in the near future. Tables 16 and 17 rank by frequency the areas flagged by respondents as opportunities for improvement in the areas of evaluation and management.

Table 16 – Data Warehousing Evaluation

OPPORTUNITIES FOR IMPROVEMENT	FREQUENCY (%) (n=21)
Benefits Analysis	6(29)
User Needs Assessments	4(19)
Performance Monitoring	3(14)
Overall Assessment	2(10)
Financial Evaluation	2(10)
Data Quality Evaluation	2(10)
Usage Evaluation	2(10)
Benchmarking	2(10)
Data Access Monitoring	1(5)

Table 17 – Data Warehousing Management

OPPORTUNITIES FOR IMPROVEMENT	FREQUENCY (%) (n=21)
Communications	3(14)
Usability	2(10)
Knowledge Sharing	1(5)
Training	1(5)
Ongoing Generation of Value	1(5)
Data Completeness and Accuracy	1(5)

5. Summary of Findings

The current section presents a summary of the findings. Tables 18 to 20 summarize the results obtained for each research question. The research questions are displayed in the first column along with their equivalent in the interview guide. The summarized findings are displayed in the second column.

Table 18 – Summary of Findings on the State of Health Data Warehousing Evaluation

RESEARCH QUESTION 1: WHAT IS THE STATE OF HEALTH DATA WAREHOUSING?	
Research question 1.1: do healthcare organizations formally evaluate their data warehouse? **Interview guide question**: in your organization is the health data warehouse evaluated? If yes, please describe. If no, why?	Seventy six percent of respondents did not perform a formal evaluation of the health data warehouse. Twenty four percent of respondents performed informal assessments.
Research question 1.2: is health data warehousing evaluation perceived as necessary? **Interview guide question**: in your organization, is health data warehouse evaluation perceived as necessary?	Seventy six percent of respondents stated that health data warehousing evaluation was not perceived as necessary by their organization. The evaluation was perceived as necessary in 24% of the surveyed organizations.
Research question 1.3: when conducted, how are the assessments performed and what do they entail? **Interview guide questions**: How do you evaluate the costs of doing data warehousing? (e.g. do you perform a financial evaluation of the data warehouse?). If yes, how? How do you evaluate the benefits of using a data warehouse (e.g. evaluating improvements in effectiveness, efficiency, etc.)? How do you evaluate the quality of the data in the data warehouse? (e.g. availability, relevance, reliability of the data)? How do you evaluate the effectiveness of the architecture of the data warehouse (e.g. flexibility, scalability, integration with other systems)? How do you evaluate the early and ongoing generation of value provided by the data warehouse? How do you evaluate the usage, usefulness, usability and performance of the data warehouse (e.g. who the users are – type of users, number of users, speed, failure rate, system availability)?	Seventy one percent of the data warehouses had not been formally evaluated from a financial standpoint (no initial cost-benefit analysis, no ROI). When a financial analysis was performed (29%), it was focused on outcomes (benefits) and was done on a project basis. Data quality was an issue acknowledged by all participants. However, assessing relevance was never mentioned and 14% of respondents said they were leaving data quality evaluation to the appreciation of users. In a limited number of cases, reliability (e.g. the concordance with the source systems) was monitored through automated validations (38%) and record counts/manual processes to match content between the source systems and the data warehouse (33%). Availability and completeness was monitored through system-generated metrics 19% of the time. Rather than being evaluated, the effectiveness of the data warehouse was monitored by 62% of respondents through a series of system-generated metrics which encompassed query response time and quality, CPU usage and system uptime. Neither scalability nor flexibility was evaluated. Ninety percent of respondents assessed the early and ongoing generation of value through metrics pertaining to the amount of active time spent by developers on the system, the time spent by users on dashboards, the number of reports accessed, and the number of dashboards and reports built. From logins to the number of queries run as well as the type and number of reports and dashboards accessed, all systems offered the capability to track usage in an automated fashion. However, rather than being formally evaluated, utilization was monitored with various degrees of regularity. Respondents did not provide a specific account of the number of users and user satisfaction was formally assessed only14% of the time.
Research question 1.4: do the assessments rely on critical success factors? **Interview guide question**: do you refer to critical success factors when you evaluate. If so, what are those factors?	The use of critical success factors was never mentioned.

Table 19 – Summary of Findings on the Use of Data warehousing to Improve Healthcare Efficiencies

RESEARCH QUESTION 2: HOW IS DATA WAREHOUSING USED TO IMPROVE HELTHCARE EFFICICIENCY?	
Research question 2.1: how s is health data warehousing used to address inefficiencies and waste? **Interview guide question**: in your organization is data warehousing used to address inefficiencies and waste? If yes, please describe. If no, why is it so?	Forty eight percent of respondents provided examples of how the data warehouse helped successfully remediate issues of waste and inefficiencies. The most cited examples pertained to excessive use of blood products, excessive use of implants, and unnecessary imaging and laboratory tests.
Research question 2.2: how is health data warehousing used to improve processes and reduce costs? **Interview guide question**: in your organization, is health data warehousing used to improve processes and reduce costs? If yes, please describe. If no, why is it so?	Seventy one percent of respondents offered examples of the use of the technology to improve processes. Patient throughput, laboratory throughput, occupancy rates and hospital acquired conditions were most often cited as areas in which the data warehouse had contributed to increased efficiency. From supply cost optimization to physician productivity tracking, pharmaceuticals consumption and cost analyses of readmission rates and lengths of stay, 95% of respondents indicated how data warehousing is used in financial and operational areas. In each of these instances the technology facilitated financial and performance analyses to assess and increase effectiveness and productivity
Research question 2.3: how is data warehousing used to address medical, clinical, nursing and research purposes? **Interview guide questions**: In your organization, is data warehousing used to address medical, clinical, nursing and research purposes? If yes, please describe. If no, why is it so?	Fifty two percent of respondents offered examples of the use of the system to improve processes with direct impact on patient care. Eighty one percent of respondents offered various accounts of the system's utilization for research purposes. These accounts included outcome research, cohort discovery and the identification of potential cohorts for clinical trials. Additionally, those affiliated with teaching institutions reported using the system to support the research requirements of their residents.

Table 20 – Summary of Findings on Evaluation Dimensions, Factors and Methods

RESEARCH QUESTION 3: HOW IS SHOULD THE EVALUATION OF HEALTH DATA WAREHOUSING BE CONDUCTED?	
Research question 3.1: which evaluation dimensions and factors should be considered? **Interview guide question**: when evaluating a health data warehouse, which dimensions and factors should be considered?	Ninety percent of respondents provided feedback on what the evaluation should entail and cited 29 components for which they determined a total of 94 factors.
Research question 3.2: which evaluation methods should be used? **Interview guide question**: when evaluating a health data warehouse, which methods should be used?	Seventy six percent of respondents provided feedback on how to conduct the evaluation and cited 14 methods and 45 evaluation items.

CHAPTER VI – DISCUSSION

The following sections synthesize the "lessons learned" by showing how the research questions were addressed, discussing the explanatory value obtained from the empirical study and the comparison of the framework with current practices, and by delineating future implications.

1. Addressing the Research Objectives and Questions

Exploration was the primary objective of the empirical study and was achieved by using semi-structured interviews to address three research questions starting with "What is the state of health data warehousing?" The study provided an answer to this question. The data warehouse system of those organizations interviewed was not formally evaluated nor was its evaluation perceived as necessary. Furthermore, Critical Success Factors (CSFs) were typically not taken into consideration. When performed, informal assessments did not involve consistent methods or standardized measures. These results may well explain why a literature review on the topic returned so few publications.

The next major finding of the empirical study is that, not only in practice but also from a theoretical standpoint, the concept of evaluation itself is very seldom considered with regard to health data warehousing. In light of this result, it is not surprising that respondents experienced difficulty in relating to the concept of evaluation when they were asked to describe its use.

This in turn indicates how evaluation, as it relates to health information systems in general and health data warehousing in particular, remains an area for which comprehensive theoretical frameworks are lacking. The absence of frameworks means there are few guidelines to assist professionals in conducting sound and objective assessments, and ultimately results in evaluation not being performed.

Using the same exploration process, the empirical study also achieved the objective of answering the second research question, "How is data warehousing used to improve healthcare efficiency?" The study showed how, from patient throughput to productivity tracking and cost optimization, data warehousing

was perceived as significantly contributing to improving the efficiency of healthcare systems. It equally showcased the positive impact of the technology in medical, clinical, and research areas. The empirical study reported notable accomplishments in the area of process improvement, and importantly it indicated how data warehousing enables such improvements.

From 1995 to 2005, productivity growth in the private industry was estimated at 2.5% annually. In healthcare, education, and social assistance it accounted for -0.2%. What characterized private industry productivity during that period was not the production of new goods but the generation of better ways to organize production and manage distribution and sales. It has been argued by some that healthcare systems, on the other hand, were marked by little to no organizational innovations (e.g. Culter, 2010). A paradigm shift has since occurred that is transforming how healthcare systems operate. Even though innovation is most often associated with products it can also apply to processes, which can lead to major shifts in organizational performance. The research in this dissertation offered multiple examples of such transformation. All participating organizations were innovating through process. In doing so they were no longer focusing on providing the best possible care to single patients but rather to all of their patients. They were following a comprehensive approach based on process rather than a fragmented one based on tradeoffs between care and other outcomes. Achieving such a comprehensive perspective relies heavily on the production of data analytics and business intelligence to support the monitoring, in-depth analysis, and forecasting of all necessary indicators. The empirical study demonstrated that data warehouses are perceived as being the best available systems to generate the needed information. Not only were they capturing data from all individual systems to provide a "single version of the truth," but they were making it available in customized and usable formats.

If innovation through process is based on standardization, the latter aims primarily at reducing variation. All participating organizations offered numerous examples of how data warehousing contributes to this effort. It was achieved in terms of the processes involved at the patient visit level and also at the medical, clinical and research levels with aspects such as patient flows, procedures, treatments, and discharge.

While motivated by an ongoing quest to improve the quality of care, the above-mentioned transformation is also an attempt to curtail ever-increasing costs. Nonetheless, it is important to note that, despite the urgency to address the financial viability of healthcare systems, the emphasis is not placed directly on financial aspects. The research confirmed this. Respondents did not report initiatives as intended to reduce costs but rather as improvement projects which eventually translated to cost reductions. The rationale behind this approach is that proper understanding of the inefficiencies at play must be gained first. This conditions the improvement of healthcare delivery which is, in turn, a prerequisite to lowering costs. As confirmed by the empirical study, a multitude of improvement initiatives are underway. However, if similar projects were occurring across all participating organizations, many projects were different, which raises the question whether all initiatives are created equal, i.e. whether they really serve the purpose of improving care for all vs. single patients. The only way to address this question is through evaluation. Whether at the data warehousing or project level, however, participants did not report the existence of a formal evaluation process meant to address the adequacy of improvement initiatives.

Similarly, even though targeted indirectly, attempts to improve patient safety and quality are also attempts at strengthening accountability and transparency. Here, because the emphasis is on care improvement, the attempts are seen primarily as concerning clinical and medical areas. However, they also apply to and will increasingly be the norm for all ancillary services, including information technologies. If the transformation of healthcare systems from volume- to value-based relies heavily on the deployment of information systems, their “meaningful use” is equally essential. Whether such use is achieved and optimized can only be determined through evaluation. In this regard, the research unveiled what can be called the paradox of health data warehousing evaluation – or the lack thereof. The technology was said to be at the center of considerable efforts to improve performance and reduce costs. It was described as a part of and a contribution to a data-driven culture based on measures. This is not only the central pillar of process improvement but also the prerequisite for sound and objective evaluation. However, the effort was not reflexive, i.e. it did not apply to data warehousing itself. The same data-driven culture was not found around the system, i.e. its evaluation was not perceived as necessary. Very few metrics were applied to the technology and fewer, if any, were defined with reference to standards and best practice,

be it to assess its use, its cost or the quality of its output. Similarly, benchmarking was almost non-existent. The technology seemed to follow the very same volume-based pattern that improvement initiatives were seeking to change in the clinical and medical areas. While the assessment of performance, efficiency and effectiveness (both technologically and in terms of use) received limited attention, in several instances increasing resources continued to be allocated to the deployment of newer technologies whose maturity was still being questioned.

The empirical study also made it possible to achieve the third objective of the research, i.e. to compare the framework developed earlier with current practices. In doing so, the study addressed the third research question, "How should the evaluation of health data warehousing be conducted?" The data collected over the course of the empirical study enabled the researcher to go above and beyond this objective. It added an explanatory value to the research. The next section describes the areas in which such value was obtained.

2. Explanatory Value of the Empirical Study

The empirical study not only provided a descriptive account of the state of health data warehousing evaluation, it confirmed some the (sic) technology's key determinants. The empirical study also unveiled some of the reasons why evaluation is not performed, providing insight into what takes place in lieu of evaluation, and indicating whether alternatives are considered for the future. The next sections offer a detailed discussion of these findings and leverage a few of the most pertinent interview excerpts which led to such conclusions.

2.1. Key Determinants of Health Data Warehousing

Three key determinants of health data warehousing were identified which reinforce the need for evaluation.

Specificity of health data. Compared with other sectors, the data found in healthcare is first and foremost voluminous. One respondent offered a description of this characteristic:

> In healthcare it's the sheer volume of tables and columns that you have. We don't have billions of encounters but we have lots of columns that describe that encounter and that patient. (R14)

Health data is not only voluminous, it is heterogeneous. It is patient-centric as it relates to patients. It is aggregated when relating to utilization and resource management. It is transformation-based when pertaining to decision support for management or clinical purposes. It is comparative when applied to health services research, outcomes measurement and population health. As a result, data sources are numerous as well (from Electronic Health Records to billing, scheduling, laboratory or imaging sources) and usually relate to specific health domains which tend to constitute silos that are hard to integrate in the data warehouse. The evaluation of system and information quality is thus particularly critical for health data warehousing.

Constantly evolving nature of health data warehousing. This aspect cannot be emphasized enough. It encompasses an array of factors from the integration of technological advances to adjustments to internal and external environments. This has a profound impact on the system by keeping it in a constant state of flux. The changes currently occurring as a result of healthcare reform further increase such volatility. This reinforces the need to make the assessment of organizational factors an intrinsic part of the evaluation framework.

Health data warehousing raison d'être. Nearly 40% of respondents deemed it possible to obtain similar results without the data warehouse while a majority (86%) saw the added value of the system in its ability to enable integration, fast delivery, and easy manipulation of data as well as the unveiling of issues otherwise left unaddressed. This finding informs evaluation in a critical manner since it helps target the areas where key net benefits can be expected.

2.2. Evaluation vs. Monitoring

Evaluation was a concept which respondents experienced difficulty in relating to and, was often confused with monitoring. As the acronym "M&E" indicates, monitoring and evaluation are usually associated. However, even though related, they are not identical. Table 18 compares their respective characteristics.

While monitoring provides input on a limited number of variables, evaluation provides the comprehensive link to the overall strategic framework including corporate vision and values. This is of particular importance in the case of data warehousing since the system impacts decision making and efficiency improvement across entire healthcare organizations.

2.3. Evaluation vs. Project Management

M&E is an integral part of program management. It is commonly used in most sectors of the economy but not applied to information technology. With regard to the latter, instead what is performed is "Monitoring and Controlling," i.e. one of the five stages of project management which consists in tracking progress and identifying gaps with initial plans (monitoring), and initiating corrective action to meet the objectives of a project (controlling).

This definition may help explain why respondents often mentioned that evaluation was not requested. It is not considered a part of project management. Similarly, it could explain why respondents often presented evaluation as justified by the existence of concerns or complaints. This reflects the "controlling" stage of project management, i.e. the emphasis on remediating project gaps.

The project-based approach was also reflected in the case of improvement initiatives supported by data warehousing. The existence and management of the technology were oftentimes defined by these initiatives. This also profoundly alters the system's evaluation and in some instances, renders it nearly irrelevant. When assessed, the data warehouse is evaluated with regard to the individual projects it supports, not in and of itself, i.e. its effectiveness, its performance, the usability of its front-end tools, or

Table 21 – Monitoring vs. Evaluation

MONITORING	EVALUATION
DEFINITION	
Monitoring is the tracking and supervision over time of ongoing activities.	Evaluation is the systematic assessment of performance, at the project or corporate level.
OBJECTIVE	
Monitoring aims at guaranteeing that activities are on course and executed within budget.	Evaluation aims at comparing impact against agreed strategic plans to determine the effectiveness, efficiency and sustainability of interventions.
SCOPE	
Monitoring is confined to the progress of activities. It involves process analysis and the control of activities to ensure proper management.	Evaluation covers the entire results chain from pre-established targets to achieved accomplishments in order to inform decision making. It not only includes input and output assessment but causality analysis to determine the degree to which achievements are accomplished and how.
TIMEFRAME	
Monitoring occurs between project initiation and implementation.	Evaluation can be either formative and take place during the development and early implementation phases, or summative and occur at the end of an operating cycle. Both methods are necessary in order to inform short- and long-term decision making.

how well it serves strategic objectives at the corporate level. One respondent clearly indicated this dependency:

> You don't so much demonstrate the value of the data warehouse in a vacuum, what you need to demonstrate is the success or failure of particular initiatives. They succeed or fail in part based on the ease and completeness of the access to the data needed to support them. We are not selling the data warehouse globally we're selling the value of the data warehouse for particular initiatives. (R14)

As a corollary, the onus to evaluate is on the owners of the initiatives. This onus risks bypassing data warehousing factors if they are not part of the evaluation conducted at the project level:

One area, users' needs assessments, logically calls for an initiative-based approach. However, in terms of evaluation, it raises the question whether the collection and analysis of these assessments involve processes that are at risk of redundancy across initiatives. Respondents emphasized the repetitive character of these processes but did not indicate any potential for streamlining:

> We do this over and over for every project and then we go through an architecting [sic] design and development to meet those user needs. (R11)

When associated with resources, the evaluation of users' needs assessments creates yet another paradox. Most of those respondents who deemed the available resources to be sufficient also stated they had not met the requirements identified by the needs assessments. This contradiction somewhat weakens the statement of sufficiency. Can resources really be sufficient if a fundamental step of the project life cycle is not, or is only partially, addressed? At the very least, the contradiction seems to confirm the volume- vs. value-based analogy made in section 1.1., that resources are spent regardless of the products-to-costs ratio.

As an evaluation factor, users' needs assessments are particularly valuable because they lend themselves to the derivation of metrics which both measure whether targets are achieved and determine where improvements are needed. In the context of the research, they enabled the testing of an additional assumption: organizations that hired external consulting firms to conduct needs assessments were those where users' needs had been met. Based on the data collected over the course of the empirical study, this assumption was not confirmed. On the other hand, several respondents reported the need to stay abreast of the latest technological advances though the use of their current systems had not yet been optimized. Suffice it to say that this is not specific to health data warehousing but pervasive throughout the information technology industry and equally applies to the latest smartphone model. This again typifies the volume- vs. value-based analogy. The recourse to external consulting firms follows a similar pattern, though based on a different rationale: the assumption that consultants alone, by the mere fact of being external to the organization, can provide expert and objective advice.

A discussion of these issues goes well beyond the context of the research. However, they were brought up by several respondents and seem well worth mentioning. More importantly, they represent an opportunity to highlight one of the long-term byproducts of evaluation, i.e. the increased awareness gained from comprehensive assessments can increase autonomy and control over business goals. This concept was summarized by one of the respondents in the following terms:

> Up until your conversation, the idea of evaluating a warehouse was typically done by a consultant or a vendor. Hearing of an objective evaluation framework that

> isn't being done to espouse a particular consultant or vendor, I'm very curious to see how that evolves so that it gives a group a fair chance at evaluating things objectively without somebody trying to sell something at the same time. (R12)

2.4. Evaluation vs. Recognition, Perceived Value and Success

When asked to describe what evaluation should entail, respondents often referred to the notion of recognition. Instead of defining assessment factors, they would state that the existence of and results obtained from the system were acknowledged and appreciated. As one respondent (R5) candidly said: "We get a pat on the back."

Along with recognition, "perceived value" was also invoked to define evaluation. The adjective perceived has its Latin roots in *per*, meaning "thoroughly," and *capere*, meaning "to grasp." In contemporary English, perceived means mentally grasping, sensing by instinct rather than fact. Unlike evaluation, perceived value is subjective in nature. It does not involve correlation with measured targets. It does not serve the broader purpose of determining what outcomes are and the conditions under which they are achieved.

In addition to recognition and perceived value, success was another concept commonly invoked by respondents to qualify the outcomes and/or impact of the health data warehouse. The research referred to CSFs on multiple occasions but did not use them in the development of the framework as CSFS appear to be essentially based on anecdotal evidence and do not offer insight into how information systems can be improved. The research also made repeated reference to the efforts of DeLone and McLean (1992, 2002, 2003) in providing a comprehensive success model based on the identification and testing of operative independent variables, and critiqued the relationship established by the authors between success and effectiveness, the lack of emphasis on the System Development Life Cycle, and the lack of guidance in determining whether success is achieved.

The explanatory value realized by the empirical study led to further questions about the notion of success itself and to posit the following twofold definition:

1. Success is the substantial attainment of predetermined net benefits measured by operationalized factors derived from the dimensions and components of an information system according to the business objectives set forth for the system at the corporate level in pursuit of an organization's mission.
2. The achievement of success cannot be established in absolute terms but rather by applying operationalized evaluation frameworks on a case-by-case basis, i.e. by evaluating each information system with regard to the environment in which it is deployed and/or used.

In practical terms, success is not achieved as a whole but in varying degrees. This raises the question of how to measure the degree of success and ultimately of the purpose of determining success. Evaluation, the assessment process leading to such a determination, is the only way to identify the extent to which success is achieved and how. It is the measurement of net benefits along with the explanation of how they were obtained that enables the discernment of needed improvements and opportunities for optimization, which is the purpose of evaluation.

The research posits that effective production of such analysis requires frameworks to represent the dimensions, components and net benefits of the information system under evaluation. It also posits that frameworks must in turn be translated into practical toolkits to operationalize the assessment.

3. Comparison of Current Practices with the Proposed Framework

Comparison must first be made between the existence of the proposed framework and the fact that formal evaluation was seldom performed. The empirical study offered an explanation of such imbalance. The interviews' in-depth analysis indicated an intuitive understanding on the part of respondents that assessments ought to be performed, but there appeared to be very little awareness of the meaning and purpose of system-wide evaluation. One of the respondents suggested a refinement on the purpose of evaluation:

> Is there a metric that shows skilled and unskilled on one axis and aware and unaware on another axis? Obviously, you want to be skilled and aware. If you're unskilled and unaware there's no way to get better. In business that's failing, you're wasting money. If you're unskilled but aware, you can do two things. You can get better or you can stop doing that work, but it's hard to stay unskilled and unaware, it's a very uncomfortable place. Without evaluation, I think there are a lot of groups which risk being unskilled and unaware. The larger the business the more there is a risk that progress in data warehousing is measured only in terms of what is spent. (R12)

Indeed, the objective of evaluation is not to determine the amount of resources spent. That is done by tracking resources at the project management level. In contrast, through the proposed framework, the dissertation posits that evaluation offers the means to demonstrate the measurable impact of the data warehouse on expected outcomes, i.e. net benefits, and their attainment through effective and efficient use of the system. Evaluation in general and the proposed framework in particular, aim at informing decision making about the system by identifying the most valuable and efficient uses of resources. Most importantly, they do so by referring to the overall strategic goals set out at the corporate level. This is of critical importance for health data warehousing since the system serves multiple interests – operational, medical, clinical, and research – across entire organizations. The dissertation posits that, ultimately, evaluation is the key determinant for generating system improvement. As with most healthcare improvement initiatives, evaluation leads to cost reduction and increased accountability and transparency for all stakeholders. Evaluation is the educative process that charts the two axes of awareness and skill suggested by respondent R12 in the quotation above. By not assessing against targets and indicators, the organization puts itself at risk of using resources to suboptimal ends, be it in financial, technical or utilization terms.

The empirical study unveiled an additional argument in response to the above-mentioned imbalance: the inherent complexity of the evaluation process. Several respondents qualified it as "difficult." There are

indeed challenges to health data warehousing evaluation. The complexity of the system and the heterogeneity of health data render their assessment particularly difficult. Evaluation methods vary depending on the factors under study. Quantifying the contributions of health data warehousing to corporate goals and health outcomes is not an easy task. Last but not least, resources must be allocated towards evaluation itself which is particularly challenging when formal assessments are not perceived as necessary. The overview of the state of health data warehousing evaluation also accounted for multiple areas for which improvements were needed. Even though identified, those needs were seldom, if at all, quantified and analyzed with regard to the entire results chain. They were however cited by respondents across most participating organizations, and so was the intuition that evaluation ought to be performed in order to address them. The absence of formal evaluation was related by respondents not only to the inherent difficulty of conducting assessments but also to the absence of guidelines. By setting up an evaluation framework the research affords such guidance.

Because formal evaluation was seldom performed, the research findings did not offer direct feedback on the structure of the proposed framework, i.e. its three dimensions, how they are broken down and the relations established between them. The difficulty experienced by participants to relate to the concept of evaluation limited the feedback even further. As mentioned earlier, in some instances, participants would not address the questions directly and instead describe the object of the evaluation rather than the evaluation process.

However, as part of the empirical study, participants were asked to designate which assessment criteria the evaluation should comprise. This finding informed the framework's content and confirmed the factors initially defined. More importantly, this finding informed the ranking of the factors. The top three criteria cited by respondents (costs analysis, benefits analysis, support to the organization's mission) were factors which belong to the framework's organizational dimension. The next three factors pertained to the impact of the system (impact on patient care, unveiling of issues otherwise unknown, financial impact) and are part of the framework's utilization dimension. Factors belonging to the technical dimension ranked in the middle (system infrastructure, usage, system management) and at the bottom (data

accuracy, data quality, data latency) of the distribution of criteria given by respondents. The predominance of the organizational and utilization dimensions over technical components was summarized by one of the respondents as follow:

> I think the evaluation isn't does somebody match perfectly the Kimbal model or does the warehouse have all the latest technology, but I would say it's the percentage of investment that is directly delivering on the most valuable component. It's not just about evaluating information technology and business intelligence, it's about evaluating the customer and knowing what the percentage of delivered results used is. (R12)

It is important to note that respondents were not asked to rank order their criteria. However, they cited them by order of importance based on their experience with the system's management in the context of their organization. Similarly, their choice of evaluation methods (monitoring, usage tracking, users' surveys) was a reflection of the methods used in the context of project management. In contrast, the proposed framework is based on evaluation principles which provide guidance for the conduct of the assessment by defining all components and factors. In doing so, it offers a structure for a comprehensive evaluation that aims at informing decision makers why results are the way they are and designating areas in need of improvement.

4. Research Limitations

As with any exploration study, three major limitations affected the empirical study: credibility, dependability and transferability.

4.1. Credibility

This refers to the ability of the researcher to acquire a proper impression of the investigated topic. It is threefold and encompasses the potential effect of the observer's presence during the study; the potentially distorting effects of the observer's perceptions and interpretation; and the observer's limited capacity to account for each and every aspect of the topic under investigation.

The researcher addressed the issue of credibility by discussing generalization concepts with respondents to confirm the plausibility of these concepts. Multiple exposures to content minimized the risk of distorting effects. From the interview sessions to their transcription, coding, and analysis, the content was reviewed in various forms, from various angles, and at various points in time. Additionally, potential biases were compensated for by paying particular attention to evidence that contradicted observations.

Having ensured the recruitment of a sufficient number of respondents increased the validity of the empirical study as well. In the absence of consensus on what constitutes a sufficient sample size, qualitative research relies on the principle of saturation, i.e. data collection is pursued until it can be determined that no new data is forthcoming. However, there is no consensus on how to establish when such state is reached. The empirical study followed the principle of saturation and the latter was deemed reached at the 21st interview. The decision was made based on several considerations. There is a general agreement that, when used for qualitative research, samples should not be smaller than 15 (Bertaux, 1981). The empirical study met this requirement. It is also commonly accepted that as long as data is collected there will always be new content emerging but that the added value of new content inevitably decreases over time. It is left to the discretion of researchers to assess this trend. To minimize the arbitrary nature of the assessment, researchers must proceed with discipline and analyze data as it is collected in order to determine the cut-off point (Strauss & Corbin, 1998). The empirical study strictly conformed to this methodology. In doing so, it was established that from the 15th interview on, the return on new content was continuously and significantly diminishing. By the 21st interview, very little distinct content was found and for only a few isolated concepts. It is also recommended that saturation be determined with reference to the coding scheme and the chronology of the codes' development (Guest, Bunce, & Johnson, 2006). All main codes were developed by the 15th interview. Three quarters of the sub-codes were developed by then as well and very few sub-codes were developed over the last six interviews. The value of qualitative data is a product of the interviewer's ability to elicit respondents' contributions and thus relies on his/her skill level and experience. It can be reasonably expected that an experienced interviewer will collect more valuable data faster (Guest, Bunce, & Johnson, 2006). The fact

that the researcher was a seasoned professional with prior academic background and professional experience, including the practice of qualitative methods, corroborates this expectation.

Lastly, a separate edition of the study design and findings was specifically assembled and disseminated to all respondents. In doing so, participants were given the opportunity to review all materials and provide feedback on areas possibly misrepresented or dealt with in an erroneous manner. Those respondents who provided feedback approved of the accounts made of their contribution and agreed with the research findings.

4.2. Dependability

This limitation refers to the replicability of observations and to the ability of another researcher to generate similar observations when repeating the procedures under similar conditions (Horsburgh, 2003; Miles & Huberman, 1994). To ensure dependability, the study design was thoroughly documented and included a complete description of all procedures.

4.3. Transferability

The data produced by exploration research is most often textual. The research method produces "text" which even though analyzed does not lend itself to statistical analysis. This in turn bears the risk of inconclusive results which cannot be generalized. By applying the principle of saturation throughout the analysis process to a highly representative sample, the risk of inconclusiveness was successfully minimized. Moreover, by enlisting the participation of the Healthcare Data Warehousing Association, the largest professional organization for the technology under study, participants' recruitment was achieved under optimal conditions. This conferred a high degree of relevance on the sample. The ability of respondents to provide pertinent information on the topic was remarkably high. Since they were based on a rigorously tailored structure, i.e. one that mirrored the research questions and involved a guide but yet offered respondents the opportunity to expand on any area as they saw fit, the interviews themselves were conducted under equally advantageous conditions (Horsburgh, 2003; Miles & Huberman, 1994).

The major limitation of the empirical study pertains to the generalization of its findings. As opposed to the statistical generalization offered by quantitative studies, generalization based on qualitative research is situational in nature, i.e. whether results can be extended to individuals in similar situations using the theory developed within a particular study (Horsburgh, 2003; Miles & Huberman, 1994). If the empirical study meets such a prerequisite, a series of limitations must be considered.

Since they were drawn from US healthcare organizations and therefore reflect their professional contexts and the views shared by their personnel, the research findings may not be generalizable to other countries, particularly those employing a different healthcare system. Even though highly representative, the organizations surveyed for this study belonged to a limited number of localities. Care must thus be exercised in generalizing the results within the United States. Moreover, the sample included only hospitals, medical centers, and health systems. Generalizing the research results to all healthcare organizations may not be appropriate, particularly in the case of state and federal departments of health or specialized segments of the industry. Similarly, only one respondent in each organization was interviewed. This raises the concern that a single respondent's view may not reflect that of an entire organization. Additionally, most of the systems in use were either still at a fairly early stage in the adoption process or undergoing substantial redesign. As these systems evolve, the opinions which respondents have of their evaluation may evolve as well.

If taking these limitations into consideration is essential, it must also be stated that the benefits of the research, i.e. the availability of actionable information on a topic never before investigated, outweigh such limitations. Unless and until they are contradicted and/or augmented by practice and additional studies, the findings presented in the next chapter represent the only body of knowledge solely dedicated to the evaluation of health data warehousing.

5. Future Directions

The implications of the research should be considered with regard to healthcare organizations, the information technology industry and research. Implications should also be considered with regard to addressing the need for result-oriented cooperation between these three entities.

5.1. Implications for Healthcare Organizations

One of the respondents summarized the immediate implication of the research:

> As you go about your day to day thinking, your budgeting and your strategic decisions, if you know what an evaluation criteria looks like, just setting yourself up so that you know the answer ahead of time, as opposed to making decisions without the benefit of an evaluation framework. People are to be able to justify what they've done. It would be better if they had the framework upfront, so that it's built in and the justification aligns to a framework as opposed to just a plea for a subjective value. (R12)

By adopting the proposed framework, it is hoped healthcare organizations would acquire the means to perform objective assessments internally. In doing so, it is argued they would gain actionable insight into resources optimization by taking stock in a systematic fashion of what is occurring and how. The empirical study provided examples of such areas which, if addressed, would lead to increased net benefits for the system and for healthcare organizations.

The extent of the contribution made by data warehousing to the improvement of healthcare efficiency is emphasized by the importance given to it by participants. Through monitoring and control, organizations are already partially tracking some of the system's key performance indicators. A formal assessment performed in a systematic fashion would likely create even more significant results.

The implications of the research go beyond data warehousing. Adjusted to other systems, the data warehousing evaluation framework could become a part of a much broader portfolio of assessments. Beyond generating additional net benefits across the entire information technology infrastructure, this would increase the strategic capability of healthcare organizations to control their environment. The healthcare sector is being impacted by a series of unprecedented changes the consequences of which are unfolding with a domino effect. The reform currently underway in the US heavily relies on information systems. A race against time is taking place with the information technology industry trying to supply the needed equipment on one hand, and healthcare organizations struggling to adopt them while having to comply with the reform's requirements on the other. Time pressure and the speed at which new products are introduced are adding unpredictability to an already volatile environment. Under such circumstances, decision making is inevitably hampered by issues and concerns the prioritization of which is increasingly difficult to establish. The availability of quantified measures of systems' performance, effectiveness and efficiency would help alleviate such unpredictability, improve decision making, increase return on investments, and provide clear and distinct feedback to the information technology industry on needed technical improvements.

5.2. Implications for the Industry

Gartner Inc., a leading US information technology research and advisory firm, makes ample use of evaluation for its business intelligence consulting portfolio. For example, Gartner Inc. recommends measuring satisfaction with data timeliness, relevancy, accuracy and consistency. The ability to use data for business decisions is also part of the assessment process which is scheduled quarterly to address the evolving nature of business intelligence. The evaluation aims at discerning data quality issues that have the greatest impact on business goals and strategy in order to prioritize solutions.

If this practice is becoming more common, the message of the industry still remains focused on technology as a panacea. As well, the market is reaching unprecedented saturation levels with digitization products and solutions whose quality and integration are increasingly hard to decipher. Fragmentation and lack of cohesion in turn obscure the clarity demanded for sound strategies. For

example, the industry impetus to utilize external sources of Big Data is seldom related to its trade-off, i.e. the diverting of resources which would otherwise be focused on the extraction and analysis of critical internal data.

According to a survey conducted by Gartner's Executive Programs and published in January 2014, 42% of CIOs lack the necessary human resources to address the requirements of digitization. The survey also indicated that information technology budgets will remain unchanged or increase only slightly (0.2%) in 2014 (Gartner Inc, 2014).

While health information systems' budgets have increased tremendously in recent years, the sustainability of this growth pattern is coming under scrutiny. Less than half of those who participated in the empirical study indicated that they had sufficient resources. A limited capacity to meet the digitization demand with increased resources will inevitably curb the tendency to outsource, and instead shift focus towards the talent and expertise found in-house.

In such a context, the adoption of sound evaluation practices is equally relevant to the industry. It holds the potential of a more adequate and effective way to reconcile supply and demand as well as meet both current and developing needs, and ultimately to avoid the threat of a looming digitization divide.

5.3. Science and Research Implications

The research in the current dissertation augmented the available body of knowledge in several ways. First, a literature review was provided on the topic. Such a review had not yet been conducted. Second, a framework was produced, i.e. a theoretical model that formalizes health data warehousing evaluation and defines its dimensions, components and factors. Third, an empirical study enabled to further investigate the topic by focusing on current practices.

Further research is still necessary to fully operationalize all factors. Moreover, a ranking and scoring structure must be developed to address the fact that some factors are more determining than others in

achieving net benefits. This would enable (sic) to conclude the evaluation process with the production of an overall score representing the proportion of attained net benefits and scores on individual factors which can be used to highlight priorities for improvement. This would also guarantee the objectivity of the assessment.

Additionally, it will be necessary to investigate the framework's application on a wide enough scale to acquire meaningful feedback on its impact. This would make available additional knowledge on the delineation between the assessment of the system itself and of the results obtained at the project level. More importantly, it would provide a basis for sound and objective benchmarking, from a technological standpoint but also in terms of healthcare efficiency improvements, by assessing such efficiencies and how they are obtained against commonly shared standards.

The science and research implications extend beyond data warehousing. The proposed framework is applicable and can be tailored to other healthcare information systems. Tailoring the proposed framework would result in an overall evaluation portfolio which would provide fact-based evidence for the analysis of the progress made towards healthcare improvement. Moreover, the proposed framework could equally be tailored to information systems in general as they apply to other industries.

Lastly, the research in the current dissertation highlights the importance of the systematic inclusion in teaching institutions' curriculum of comprehensive courses on information systems' evaluation. Out of the top 150 health informatics programs currently offered by academic institutions in the US, only 28 include courses on health information systems evaluation.

5.4. Need for Result-Oriented Cooperation between Actors

Paradoxically, in an era characterized by the ability to share massive amounts of information in record time, effective and result-oriented cooperation between actors remains challenging. Rather than the purposeful blending of strengths, isolated approaches continue to prevail and with them the yielding of counterproductive results. While the production of systems lacking effectiveness persists, some of

healthcare organizations' key needs remain unaddressed and a wealth of knowledge remains locked in academic environments.

Far from being an idealistic aspiration, result-oriented cooperation is the only effective way of enabling methods such as benchmarking, the dissemination of best practices and the adoption of standards. The improvement of healthcare efficiency is by definition an area that calls for multidisciplinary initiatives involving the coordinated contribution from areas ranging from health policy to information science.

With regard to health data warehousing, the Healthcare Data Warehousing Association has facilitated the exchange and communication between actors in the healthcare industry for over a decade. Its membership base is unparalleled, both in terms of expertise and experience, and includes academic centers. The association has proved an invaluable platform for the empirical study and constitutes an ideal research environment. It is uniquely positioned to set the agenda of and host result-oriented cooperation to coordinate the definition, adoption and assessment of standards by and for healthcare organizations, the data warehousing industry and academic centers.

CONCLUSION

The research bridges a key information gap from several standpoints. First, a literature review is presented that shows the absence of treatment of health data warehousing evaluation by official publications. Next, a review of applicable theoretical models is offered that discusses the DeLone and McLean model of Information System Success and emphasizes the need for inclusive evaluation frameworks. Third, the research presents the construct of such framework, including the definition of its individual factors. Lastly, an empirical study further explores the state of health data warehousing evaluation and the use of the technology to improve healthcare efficiency. Based on semi-structured interviews, the study collects data from 21 executive and upper-level management professionals in charge of business intelligence and data analytics at major US healthcare systems. The study not only shows that formal evaluations of the system are seldom performed, it also highlights explicit and implicit reasons for the lack of formal assessment, i.e. why it is not done and what is done instead.

The research also has a broader implication. Those organizations which have been able to leverage data warehousing to significantly improve healthcare have done so at the expense of lengthy and painstaking efforts. Bringing sustainability to healthcare systems is an urgent issue throwing actors into a race against time. Alleviating the time pressure while avoiding reinventing the wheel are of the essence and require frameworks to enable advances in analytics, process improvement and patient care standardization to be readily compared, understood and broadly adopted. The research contributes to this vital improvement by offering a basis for benchmarking in one area, i.e. data warehousing, while giving actors the means to improve their use of the technology.

Lastly, the integration of a plurality of factors had been identified as one of the areas in need of further development in order to advance information systems evaluation research. The research advances this by providing a framework that integrates from five different perspectives:

Plurality of users. Health data warehousing is destined for use by decision makers in all areas of healthcare, from clinical to financial, operational and research, and therefore serves a broad range of users with varied backgrounds and areas of expertise. The assessment of the technology therefore offers the opportunity to take this plurality of users into account while addressing the direct impact on the care provided.

Plurality of systems. Since data warehousing is made up of and depends on various applications, its evaluation is by definition multi-system.

Plurality of phases. From design to implementation, health data warehousing requires a considerable amount of time and the use of the technology serves a long-term perspective. Consequently, its evaluation cannot be limited to a single point in time and offers the opportunity to conduct the assessment within a broader timeframe and by taking a plurality of phases into account.

Plurality of findings. Assessments are the prerequisite to understanding the causes of negative outcomes and to the improvement of unsatisfactory results. The transparent reporting of such assessments offers practical demonstration of the benefits of integrating a plurality of findings.

Plurality of methods. If quantification is at the core of sound evaluation, the understanding of factors such as roles, norms and values cannot be reduced to quantitative measures. The multiple dimensions and components of health data warehousing evaluation illustrate the need for and justification of the simultaneous use of various methodologies.

Further research in the above areas is warranted as data warehousing becomes more widely deployed internationally. Furthermore, in order to improve the effectiveness of these systems the sharing of information obtained from their evaluation will become increasingly important.

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APPENDIX A – FRAMEWORK'S THEORETICAL REFERENCES

SYSTEM QUALITY	
DELONE AND MCLEAN IS SUCCESS MEASURES	**FRAMEWORK FACTORS**
	TECHNOLOGICAL DIMENSION: COMPONENT 2A
DATA ACCURACY	DATA ACCURACY (FACTOR 2A-7.1.)
DATA CURRENCY	DATA CURRENCY (FACTOR 2A-6.)
DATABASE CONTENTS	DATA MARTS CONTENT (FACTOR 2A-4.1.)
SYSTEMS INTEGRATION	ETL INTEGRATION LAYER (FACTOR 2A-1.2.)
	TECHNOLOGICAL DIMENSION: COMPONENT 2B
SYSTEM FLEXIBILITY	SYSTEM FLEXIBILITY (FACTOR 2B-1.)
SYSTEM RELIABILITY	SYSTEM RELIABILITY (FACTOR 2D-1.)
SYSTEM SOPHISTICATION	SYSTEM SOPHISTICATION (FACTOR 2B-4)
	TECHNOLOGICAL DIMENSION: COMPONENT 2A, 2D
TURNAROUND TIME, RESPONSE TIME	RESPONSE/TURNAROUND TIME (FACTOR 2D-1.1.)
CONVENIENCE OF ACCESS	DATA ACCESSIBILITY (FACTOR 2A-3.)
	ORGANIZATIONAL DIMENSION: COMPONENTS 1C, 1D, 1E
SYSTEM EFFICIENCY	USE OF FINANCIAL RATIOS AND ANALYSES (FACTOR 1C-2.)
RESOURCE UTILIZATION	BUDGET PREPARATION AND MONITORING (FACTOR 1C-1.)
HUMAN FACTORS	USER NEEDS ASSESSMENT (FACTORS 1D-1 TO 5) USER SUPPORT (FACTORS 1E-1 TO 6)
REALIZATION OF USERS REQUIREMENTS	USER NEEDS ASSESSMENT (FACTORS 1D-1 TO 5)
	UTILIZATION DIMENSION: COMPONENTS 3A, 3B, 3C
EASE OF LEARNING	EASE OF LEARNING (FACTOR 3A/B/C-1.5.1)
EASE OF USE	EASE OF USE (FACTOR 3A/B/C-1.5.)
USEFULNESS OF SYSTEM'S FEATURES AND FUNCTIONS	USEFULNESS (FACTOR 3A/B/C-1.6.)
SYSTEM ACCURACY	NOT USED (FACTOR CONSIDERED REDUNDANT)

INFORMATION QUALITY	
DELONE AND MCLEAN IS SUCCESS MEASURES	**FRAMEWORK FACTORS**
	UTILIZATION DIMENSION: COMPONENTS 3A, 3B, 3C
ACCURACY	ACCURACY (FACTOR 3A/B/C-2.1.)
APPEARANCE	APPEARANCE (FACTOR 3A/B/C-2.2.)
CLARITY	CLARITY (FACTOR 3A/B/C-2.2.3.)
COMPARABILITY	COMPARABILITY (FACTOR 3A/B/C-2.3.)
COMPLETENESS	COMPLETENESS (FACTOR 3A/B/C-2.4.)
CONCISENESS	CONCISENESS (FACTOR 3A/B/C-2.5.)
CURRENCY	CURRENCY (FACTOR 3A/B/C-2.7.)
FORMAT	FORMAT (FACTOR 3A/B/C-2.2.1.)
IMPORTANCE	IMPORTANCE (FACTOR 3A/B/C-2.8.)
	UTILIZATION DIMENSION: COMPONENTS 3A, 3B, 3C
INFORMATIVENESS	INFORMATIVENESS (FACTOR 3A/B/C-2.9.)
PRECISION	PRECISION (FACTOR 3A/B/C-2.10.)
QUANTITATIVENESS	QUANTITATIVENESS (FACTOR 3A/B/C-2.11.)
READABILITY	READABILITY (FACTOR 3A/B/C-2.2.4.)
RELEVANCE	RELEVANCE (FACTOR 3A/B/C-2.12.)
RELIABILITY	RELIABILITY (FACTOR 3A/B/C-2.13.)
SUFFICIENCY	SUFFICIENCY (FACTOR 3A/B/C-2.14.)
TIMELINESS	TIMELINESS (FACTOR 3A/B/C-2.15.)
UNDERSTANDABILITY	UNDERSTANDABILITY (FACTOR 3A/B/C-2.16.)
UNIQUENESS	UNIQUENESS (FACTOR 3A/B/C-2.17.)
USABILITY	USABILITY (FACTOR 3A/B/C-1.5.3.)
USEFULNESS	USEFULNESS (FACTOR 3A/B/C-2.18.)
CONTENT FREEDOM FROM BIAS	NOT USED (FACTORS CONSIDERED REDUNDANT)

SERVICE QUALITY	
DeLONE AND McLEAN IS SUCCESS MEASURES	**FRAMEWORK FACTORS**
	ORGANIZATIONAL DIMENSION: COMPONENT 1D, 1E
EMPATHY	CUSTOMER RELATIONS (FACTOR 1E-6.)
RESPONSIVENESS	CHANGE REQUESTS PROCESS (FACTORS 1D-4.; 3A/B/C-3.1.) NEW DEVELOPMENT REQUESTS PROCESS (FACTORS 3A/B/C-3.2.)
ASSURANCE	NOT USED (FACTOR CONSIDERED REDUNDANT)

USER SATISFACTION	
DeLONE AND McLEAN IS SUCCESS MEASURES	**FRAMEWORK FACTORS**
	UTILIZATION DIMENSION: COMPONENTS 3A, 3B, 3C
OVERALL SATISFACTION	OVERALL USER SATISFACTION (FACTOR 3A/B/C-4.1.)
SATISFACTION WITH SPECIFICS	SPECIFIC USER SATISFACTION (FACTOR 3A/B/C-4.2.)
ENJOYMENT	ENJOYMENT (FACTOR 3A/B/C-4.3.)
SOFTWARE SATISFACTION	FRONT-END TOOL (FACTOR 3A/B/C-4.2.1.)
INFORMATION SATISFACTION	ASPECT OF OUTPUT INFORMATION (FACTOR 3A/B/C-4.2.3.)
DECISION-MAKING SATISFACTION	AID WITH DECISION-MAKING (FACTOR 3A/B/C-4.2.2.)
SINGLE-ITEM MEASURE	NOT USED (FACTORS CONSIDERED REDUNDANT)
MULTI-ITEM MEASURE	

USE	
DeLONE AND McLEAN IS SUCCESS MEASURES	**FRAMEWORK FACTORS**
	UTILIZATION DIMENSION: COMPONENTS 3A, 3B, 3C
PURPOSE OF USE	PURPOSE OF USE (FACTOR 3A/B/C-5.)
AMOUNT OF USE	AMOUNT OF USE (FACTOR 3A/B/C-1.1.)
AMOUNT OF CONNECT TIME	
FREQUENCY OF ACCESS	
# OF RECORDS ACCESSED	
# OF FUNCTIONS USED	
# OF INQUIRIES	
# OF REPORTS GENERATED	
FREQUENCY OF REPORT REQUEST	
DURATION OF USE	DURATION OF USE (FACTOR 3A/B/C-1.2.)
MOTIVATION TO USE	MOTIVATION OF USE (FACTOR 3A/B/C-1.3.)
NATURE OF USE	NATURE OF USE (FACTOR 3A/B/C-1.4.)
ROUTINIZATION OF USE	
RECURRING USE	
ACTUAL USE VS. REPORTED	
DIRECT VS. CHAUFFEURED USE	
PERCENTAGE USED	
	ORGANIZATIONAL DIMENSION: COMPONENT 1C
CHARGES FOR SYSTEM USE	CHARGES FOR SYSTEM USE (FACTOR 1C-3)
REPORT ACCEPTANCE	NOT USED (FACTORS CONSIDERED REDUNDANT)
VOLUNTARINESS OF USE	
APPROPRIATE USE	
BINARY USE (USE VS. NONUSE)	
LEVEL OF USE (GENERAL VS. SPECIFIC)	
USE FOR INTENDED PURPOSE	
TYPE OF INFORMATION USED	

INDIVIDUAL NET BENEFITS	
DELONE AND MCLEAN IS SUCCESS MEASURES	**FRAMEWORK FACTORS**
	INDIVIDUAL NET BENEFITS: COMPONENTS 5A, 5B, 5C
INFORMATION AWARENESS, RECALL, UNDERSTANDING	IMPROVED INFORMATION AWARENESS, RECALL AND UNDERSTANDING (FACTOR 4A/B/C-1.)
PROBLEM IDENTIFICATION	IMPROVED ABILITY TO IDENTIFY PROBLEMS (FACTOR 4A/B/C-2.)
ACCURATE INTERPRETATION	IMPROVED ABILITY TO INTERPRET ISSUES ACCURATELY (FACTOR 4A/B/C-3.)
TASK PERFORMANCE	IMPROVED TASK PERFORMANCE (FACTOR 4A/B/C-4.)
IMPROVED INDIVIDUAL PRODUCTIVITY	IMPROVED PRODUCTIVITY (FACTOR 4A/B/C-5.)
INDIVIDUAL POWER OR INFLUENCE	INCREASED POWER AND/OR INFLUENCE (FACTOR 4A/B/C-6.)
CAUSES MANAGEMENT ACTION	TRIGGERING OF MANAGEMENT ACTION (FACTOR 4A/B/C-7.)
DECISION EFFECTIVENESS	IMPROVED DECISION EFFECTIVENESS (FACTOR 4A/B/C-8.)
IMPROVED DECISION ANALYSIS	IMPROVED ANALYSIS CAPABILITY (FACTOR 4A/B/C-8.2.)
CONFIDENCE IN DECISION	INCREASED CONFIDENCE IN DECISIONS (FACTOR 4A/B/C-8.3.)
CHANGE IN DECISION	TRIGGERING OF POSITIVE CHANGES IN DECISIONS (FACTOR 4A/B/C-8.4.)
CORRECTNESS OF DECISION	INCREASED CORRECTNESS OF DECISIONS (FACTOR 4A/B/C-8.5.)
DECISION QUALITY	INCREASED QUALITY OF DECISIONS (FACTOR 4A/B/C-8.6.)
TIME TO MAKE DECISION	SHORTENED TIME TO DECISIONS (FACTORS 4A/B/C-8.7.)
DECISION-MAKING PARTICIPATION	INCREASED DECISION-MAKING PARTICIPATION (FACTOR 4A/B/C-8.8.)
LEARNING	LEARNING (FACTOR 4A/B/C-9.)
QUALITY OF PLANS	NOT USED (FACTORS CONSIDERED REDUNDANT)
PERSONAL VALUATION OF IS	
WILLINGNESS TO PAY FOR INFORMATION	

ORGANIZATIONAL NET BENEFITS	
DELONE AND MCLEAN IS SUCCESS MEASURES	**FRAMWORK FACTORS**
	TECHNOLOGICAL DIMENSION: COMPONENT 2C
APPLICATION PORTFOLIO	APPLICATION PORTFOLIO (FACTOR 2C-1)
RANGE AND SCOPE OF APPLICATION	
NUMBER OF CRITICAL APPLICATIONS	
	ORGANIZATIONAL NET BENEFITS: COMPONENTS 5A, 5B, 5C
CONTRIBUTION TO ACHIEVING GOALS	CONTRIBUTION TO ACHIEVING THE ORGANIZATION'S GOALS AND MISSION (FACTORS 5A/B/C-1.)
INCREASED MARKET SHARE	INCREASED MARKET SHARE (FACTORS 5A-9.; 5B-14.; 5C-12.)
INCREASED PROFITS	INCREASED PROFIT (FACTORS 5A-10.; 5B-15; 5C-13)
INCREASED REVENUES	INCREASED REVENUE (FACTORS 5A-11.; 5B-16.; 5C-14.)
INCREASED WORK VOLUME	INCREASED WORK VOLUME (FACTORS 5A-12.; 5B-17.; 5C-15.)
OVERALL PRODUCTIVITY GAINS	PRODUCTIVITY GAINS (FACTORS 5A-14.; 5B-19.; 5C-17.)
OPERATING COSTS REDUCTION, STAFF REDUCTION	COST REDUCTIONS (FACTORS 5A/B-2.; 5C-3.)
SERVICE EFFECTIVENESS	IMPROVED HEALTHCARE SERVICE EFFECTIVENESS (FACTORS 5B-8.; 5C-6.)
	ORGANIZATIONAL DIMENSION: COMPONENT 1C
COST/BENEFIT RATIO	COST-BENEFIT RATIO/ANALYSIS (FACTOR 1C-2.1.)
RETURN ON ASSETS, ROI,	RETURN ON ASSETS, ROI ANALYSIS (FACTOR 1C-2.3.)
RATIO OF NET INCOME TO OPERATING EXPENSES	RATIO OF NET INCOME TO OPERATING EXPENSES (FACTOR 1C-2.4.)
PRODUCT QUALITY	NOT USED (FACTORS CONSIDERED REDUNDANT)
INCREASED SALES	
STOCK PRICE	

APPENDIX B – AVAILABLE SURVEY ITEMS

FACTORS	REFERENCES
DIMENSION #1: ORGANIZATIONAL DIMENSION	
Component #1E: User Support	
1E-1. Training programs	Blanton, Watson, & Moody, 1992; Jiang, Klein, & Carr, 2002; McGill & Klobas, 2005; McGill, Hobbs, & Klobas, 2003.
1E-2. Documentation	Blanton et al., 1992; Chang & King, 2003; McGill & Klobas, 2005; McGill et al., 2003.
1E-3. Technical support	Blanton et al., 1992; Chang & King, 2003; Kettinger & Lee, 1997; McGill & Klobas, 2005; McGill et al., 2003; Pitt, Watson, & Kavan, 1995; Shaw, DeLone, & Niederman, 2002; Wixom & Watson, 2001.
1E-6. Project team skills	Blanton et al., 1992; Chang & King, 2003; Pitt et al., 1995; Shaw et al., 2002; Wixom & Watson, 2001.
DIMENSION #2: TECHNOLOGICAL DIMENSION	
Component #2A: Data	
2A-1.2. Integration layer	Chang & King, 2003; Livari, 2005; Wixom & Watson, 2001.
2A-3. Data accessibility	Kraemer, Danziger, Dunkle, & King, 1993.
2A-5. Data completeness	Wixom & Watson, 2001.
2A-6. Data currency	Rivard, Poirier, Raymond, & Bergeron, 1997.
2A-7.1. Data accuracy	Wixom & Watson, 2001.
2A-7.2. Data consistency	Wixom & Watson, 2001.
2A-7.4. Data correctness	Chang & King, 2003.
2A-9. Data reliability	Wixom & Watson, 2001.
Component #2B: Architectural Choices	
2B-1. System flexibility	Chang & King, 2003; Livari, 2005; Shaw et al., 2002; Wixom & Watson, 2001.
2D-1. System reliability	Chang & King, 2003; Goodhue & Thompson, 1995; Kositanurit, Ngwenyama, & Osei-Bryson, 2006; Rivard et al., 1997; Shaw et al., 2002; Weill & Vitale, 1999.
2B-4. Security rules	McGill & Klobas, 2005; McGill et al., 2003; Rivard et al., 1997.
Component #2D: Performance	
2D-1.1. Response/turnaround time	Kraemer et al., 1993; Law & Ngai, 2007; Livari, 2005; Palmer, 2002; Rivard et al., 1997; Shaw et al., 2002; Wu & Wang, 2006; Yuthas & Young, 1998.
2D-1.4. System availability and use	Chang & King, 2003; Yuthas & Young, 1998.
DIMENSION #3: UTILIZATION DIMENSION	
Component #3A: Financial and Operational Utilization	
Component #3B: Medical/Clinical/Nursing Utilization	
Component #3C: Research Utilization	
3A/B/C-1. Front-end tools	
3A/B/C-1.1. Amount of use	Agarwal & Prasad, 1997, 1999; Almutairi & Subramanian, 2005; Clay, Dennis & Ko, 2005; Hsieh & Wang, 2007; Livari, 2005; McGill & Klobas, 2005; McGill et al., 2003; Palmer, 2002; Stake, 1995; Subramanian, 1994.
3A/B/C-1.5. Ease of use	Agarwal & Prasad, 1997, 1999; Almutairi & Subramanian, 2005; Chang & King, 2003; Cheung & Lee, 2005; Davis, 1989; Goodhue & Thompson, 1995; Hsieh & Wang, 2007; Igbaria & Tan, 1997; Kositanurit et al., 2006; Law & Ngai, 2007; Livari, 2005; Mao & Ambrose, 2004; McGill & Klobas, 2005; McGill et al., 2003; Palmer, 2002; Rivard et al., 1997; Seddon & Kiew, 1994; Subramanian, 1994; Weill & Vitale, 1999; Wixom & Watson, 2001; Wu & Wang, 2006.
3A/B/C-1.5.3E. Error tolerance	Kositanurit et al., 2006; Law & Ngai, 2007; Livari, 2005; McGill & Klobas, 2005; McGill et al., 2003; Rivard et al., 1997; Seddon & Kiew, 1994.
3A/B/C-1.6. Usefulness	Agarwal & Prasad, 1997, 1999; Davis, 1989; Igbaria & Tan, 1997; Kraemer et al., 1993; Kulkarni, Ravindran, & Freeze, 2007; Livari, 2005; Mao & Ambrose, 2004; Rai et al., 2002; Seddon & Kiew, 1994; Torkzadeh & Doll, 1999.
3A/B/C-5. Purpose of use	Doll & Torkzadeh, 1988; Igbaria & Tan, 1997; Wu & Wang, 2006.
3A/B/C-2. Output information	
3A/B/C-2.1. Accuracy	Belcher & Watson, 1993; Chang & King, 2003; Cheung & Lee, 2005; Jiang, Klein, & Carr, 2002; Livari, 2005; Shaw et al., 2002; Yuthas & Young, 1998.
3A/B/C-2.2. Appearance	Chang & King, 2003; Cheung & Lee, 2005; Kositanurit et al., 2006; Law & Ngai, 2007; Livari, 2005; Seddon & Kiew, 1994; Yuthas & Young, 1998.
3A/B/C-2.4. Completeness	Belcher & Watson, 1993; Chang & King, 2003; Jiang, Klein, & Carr, 2002; Kettinger & Lee, 1997; Kositanurit et al., 2006; Livari, 2005; McGill & Klobas, 2005; McGill et al., 2003; ; Palmer, 2002; Rivard et al., 1997; Seddon & Kiew, 1994; Yuthas & Young, 1998.
3A/B/C-2.7. Currency	Belcher & Watson, 1993; Chang & King, 2003; Guimaraes & Igbaria, 1997; Kraemer et al., 1993; Law & Ngai, 2007; Seddon & Kiew, 1994.
3A/B/C-2.10. Precision	Jiang et al., 2002; Kositanurit et al., 2006; Kraemer et al., 1993; Law & Ngai, 2007; Livari, 2005; McGill & Klobas, 2005; McGill et al., 2003; Rai et al., 2002; Seddon & Kiew, 1994; Shaw et al., 2002.
3A/B/C-2.12. Relevance	Belcher & Watson, 1993; Chang & King, 2003; Clay et al., 2005; Jiang et al., 2002;

	Kettinger & Lee, 1997; Yuthas & Young, 1998.
3A/B/C-2.13. Reliability	Belcher & Watson, 1993; Chang & King, 2003; Cheung & Lee, 2005; Jiang et al., 2002; Kettinger & Lee, 1997.
3A/B/C-2.15. Timeliness	Chang & King, 2003; Kositanurit et al., 2006; Law & Ngai, 2007; Livari, 2005; McGill & Klobas, 2005; Seddon & Kiew, 1994; Yuthas & Young, 1998.
3A/B/C-2.17. Uniqueness	Davis, 1989.
3A/B/C-2.18. Usefulness	Chang & King, 2003; Cheung & Lee, 2005; Clay et al., 2005; Rai et al., 2002; Wu & Wang, 2006; Yuthas & Young, 1998.
3A/B/C-2.20. Volume	Chang & King, 2003; Kositanurit et al., 2006; Kraemer et al., 1993; Law & Ngai, 2007; Livari, 2005; Yuthas & Young, 1998.
3A/B/C-3.System service	
3A/B/C-3.1. Change requests process 3A/B/C-3.2. New development requests process	Chang & King, 2003; DeLone & McLean (2003); Kettinger & Lee, 1997; Kositanurit et al., 2006; Pitt et al., 1995, Shaw et al., 2002.
3A/B/C-3.3. Customer relations	Chang & King, 2003; Goodhue & Thompson, 1995; Jiang et al., 2002; Kettinger & Lee, 1997; Pitt et al., 1995; Shaw et al., 2002.
3A/B/C- 4. User satisfaction	Chang & King, 2003; Clay et al., 2005; Goodhue & Thompson, 1995; Kositanurit et al., 2006; Kulkarni et al, 2007; Law & Ngai, 2007; McGill & Klobas, 2005; McGill et al., 2003; Seddon & Kiew, 1994.
INDIVIDUAL NET BENEFITS	
	Agarwal & Prasad, 1997, 1999; Almutairi & Subramanian, 2005; Bailey & Pearson, 1983; Baroudi & Orlikowski, 1987; Belcher & Watson, 1993; Blanton et al., 1992; Chang & King, 2003; Chau & Hu, 2002; Clay et al., 2005; Davis, 1989; Gill, 1995; Goodhue & Thompson, 1995; Igbaria & Tan, 1997; Kositanurit et al., 2006; Kulkarni et al., 2007; Lassila & Brancheau, 1999; Livari, 2005; Mao & Ambrose, 2004; McGill & Klobas, 2005; McGill et al., 2003; Rai et al. 2002; Rivard et al., 1997; Seddon & Kiew, 1994; Shaw et al., 2002, Subramanian, 1994; Torkzadeh & Doll, 1999; Wixom & Watson, 2001; Wu & Wang, 2006.
ORGANIZATIONAL NET BENEFITS	
	Almutairi & Subramanian, 2005; Byrd et al., 2007; Chang & King, 2003; Doll & Torkzadeh, 1988; Torkzadeh & Doll, 1999.

APPENDIX C: EMPIRICAL STUDY - LETTER OF INVITATION

Dear HDWA Member,

The Healthcare Data Warehousing Association (HDWA) Advisory Board has reviewed the PhD research proposal of Marianne Leenaert and has endorsed Marianne's request to contact several HDWA organizations to participate in this study. Her primary objective is to assess the state of healthcare data warehousing evaluation.

If you would like to participate, **please respond (or designate someone else within your organization) to her request at the email or phone number listed on her invitation below.** The respondents and their organizations will remain anonymous but HDWA will be mentioned as a participating association. Marianne will present the structure of her project at the 2013 HDWA Conference (Banner Health) and will provide the results and summary of her research at the 2014 Conference (MaineHealth). The results will also be published in the Library found on the HDWA Website.

Thanks,

Lee

Lee Pierce

Chairman, HDWA Advisory Board

Intermountain Healthcare

AVP, Business Intelligence and Analytics

801-442-3734 (o)

lee.pierce@imail.org

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Dear HDWA Organization,

As a PhD candidate and in fulfillment of my dissertation, I am conducting a research on health data warehousing evaluation. The study has been fully endorsed by the Healthcare Data Warehousing

Association and as such has authorized me to contact you for potential participation. The research is supervised at the School of Health Information Science of the University of Victoria in British Columbia. The purpose of the research is to assess the state of health data warehousing evaluation.

Because of your involvement in health data warehousing, I would like to invite you or someone within your organization that you feel is better qualified or able to participate in the study. The latter will consist in a semi-structured phone or online (using Skype) interview scheduled at a date and time most suitable for you. The interview will take between one and one and a half hour to complete and compensation for participating in the research will consist in a Starbucks gift card.

Since this investigation has not been attempted yet, the study will contribute to the advancement of health information systems and evaluation research.

Your participation would be greatly appreciated. **If it is of interest to you or if you have any question, feel free to reply to me by email at mfl@uvic.ca. You can also contact me by phone at (250) 580-5257.**

Sincerely,

Marianne Leenaerts

Marianne Leenaerts

Email: mfl@uvic.ca

Phone: (250) 580-5257

University of Victoria School of Health Information Science

PO Box 3050 STN CSC

Victoria, British Columbia V8W 3P5, Canada.

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APPENDIX D: EMPIRICAL STUDY - CONSENT FORM

Participant Consent Form

A Proposed Framework for the Evaluation of Health Data Warehousing

You are invited to participate in a study entitled "A Proposed Framework for the Evaluation of Health Data Warehousing" that is conducted by Marianne Leenaerts, a PhD candidate with the School of Health Information Science at the University of Victoria. If you have any question, you may contact her at any time by email at mfl@uvic.ca or by phone at (250) 580-5257.

The research is conducted under the supervision of Dr. Andre Kushniruk and Dr. Alex Kuo. You may contact Dr. Kushniruk by email at andrek@uvic.ca and Dr. Kuo at akuo@uvic.ca.

Purpose and Objectives

The aim of the proposed research is threefold:

- To investigate the state of health data warehousing evaluation;
- To introduce a health data warehousing success model and its translation into an inclusive evaluation framework;
- To offer insight into the use of health data warehousing as a means to improve healthcare efficiency, into the predominance of clear evaluation guidelines over Critical Success Factors, and into the need for comprehensive health information systems evaluation frameworks.

Importance of this Research

Using a qualitative method, i.e. semi-structured interviews, the empirical study will investigate the state of health data warehousing evaluation. To do so, it will address a series of research questions with regard to the assessment of the technology. Particular attention will be devoted to the use of the system to address issues of inefficiencies, waste and process improvements. Moreover, the study will compare and contrast the results of this investigation with the proposed success model and evaluation framework. This

will include a gap analysis and the provision of recommendations to address the diagnosed gaps. Through the exploratory research as well as the development of a success model and an evaluation framework – an investigation that has not been attempted yet - the study will contribute to the advancement of health information systems and evaluation research by providing insight into the use and evaluation of health data warehousing, into the predominance of clear evaluation guidelines over Critical Success Factors, and into the need for comprehensive health information systems evaluation frameworks.

Participants Selection

You are being asked to participate in this study because of your involvement in health data warehousing.

What is involved?

If you agree to voluntarily participate in this research, your participation will consist in taking part in a phone or online (using Skype) interview. The interview will take between one and one and a half hour to complete. It will be audio-recorded and written notes will be taken. The audio-tapes will be transcribed for analysis. You may answer some, all or none of the questions. Your responses will be used by the researcher to study the evaluation of health data warehousing.

Risks

No known risks are anticipated to occur during this research.

Benefits

The benefits of your participation lie in its contribution to assessing the state of health data warehousing evaluation, to developing an inclusive framework for the system's assessment, and to bridging key information gaps in the area of health data warehousing evaluation.

Voluntary Participation

Your participation in this research must be completely voluntary. You may withdraw from the study at any time without any consequences or any explanation. If you decide to withdraw from the study your data will not be used and will be destroyed.

Confidentiality and Anonymity

All information collected will be kept strictly confidential. Thus, participant names, organizational affiliations, and any other identifying information will not be used in the research or study findings. Audio recordings will be stored in a secure, locked cabinet. Interview notes and transcriptions of the recordings will be securely stored on a password protected computer that only the researcher can access. Your name will not appear on any documentation, and any identifying data will be removed during data transcription and will not appear in the final dissertation or any published materials.

Dissemination of Results

It is anticipated that the results of this study may be shared with others in the following ways: published articles (print, Internet, media), dissertation, class presentations and/or scholarly meetings.

Disposal of Data

Data from this study will be disposed of by deleting all electronic files or shredding paper documents. All notes, questionnaires, and audio recordings will be destroyed once the final dissertation is accepted.

Contacts

Individuals that may be contacted regarding this study include Marianne Leenaerts (researcher) and Dr. Andre Kushniruk or Dr. Alex Kuo (Supervisors). Please refer to the beginning of the consent form for contact information.

In addition, you may verify the ethical approval of this study, or raise any concerns, by contacting the Human Research Ethics Office at the University of Victoria (250-472-4545 or ethics@uvic.ca).

I will sign below indicating that you understand the above conditions of participation in this study and that you have had the opportunity to have your questions answered by the researcher.

_____ (Researcher to provide initials)

Name of Participant	*Participant Signature*	*Date*
Name of Researcher	*Researcher Signature*	*Date*

APPENDIX E: EXPLORATORY CODING SCHEME

EXPLORATORY CODING SCHEME	
CODES	**SUB-CODES**
TYPE OF DATA WAREHOUSE	Multiple data w arehouses
	Non-traditional model
	Kimbal star schema
	Inmon 3rd Normal Form
	100% self-served
MIX (NON)VENDOR COMPONENTS	Completely home built
	Vendor mix
	Completely pre-built
	Open source
	MS SQL database
	Oracle database
	Tableau
	Cognos
	Business Objects
	Netezza
	Cogito
	Informatica
	I2B2
	Sharepoint
	Microstrategy
	Infosphere
	Netshare
	McKesson
	SAS
	OBIEE
	Crystal report
BUSINESS GOALS	Meet reporting needs
	Healthcare reform
	Enable clinical research
	Organization's mission and strategic goals
	Improve patient care
	Operations and Financial Analysis
	Information provision
	Data integration
	Reduce costs
	Patient and physician population identificat
	Data acquisition
	Data transparency
	Process improvement
	ICD9-10 transition
SPONSORSHIP	Yes
	Steering committee
	Spotty
	Poor initial sponsorship
	Organizational readiness
	Project-based
	Board approval
RESOURCES	FTEs
	Operating budget
	Capital expenditure

EXPLORATORY CODING SCHEME (Cont'd)	
CODES	**SUB-CODES**
SUFFICIENT RESOURCES	No
	Yes
TYPE OF USERS	Secondary users
	Clinicians
	Pow er users
	Operations personnel
	Research personnel
	Ad hoc users
	Physicians
NUMBER OF USERS	Pow er users
	Secondary users
	Percentage
PERFORMED EVALUATION	No evaluation performed
	ROI
	Project-based
	Value to the organization
	Time freed
	FTE saved
	Primary indicators
	Data quality validation
	Migration evaluation
REFERENCE TO CSFs	None used
	Project-based
	Ease of querying data
	Uptime stability
	Sponsorship
EVALUATION PERCEIVED AS NECESSARY	No
	Financial reason
	May be
	Quality reason
USE OF DATA WAREHOUSING TO ADDRESS INEFFICIENCY	Hospital acquired infections
USE OF DATA WAREHOUSING TO ADDRESS WASTE	Excessive use of blood products
	Excessive use of implants
	Unnecessary X-Rays
	Unnecessary lab tests
	Not done
USE OF DATA WAREHOUSING TO IMPROVE PROCESSES	Patient throughput time
	Performance improvement
	Quality improvement
	Call volume
	Lab throughput time
	Occupancy rate
USE OF DATA WAREHOSING TO REDUCE COSTS	Supply costs optimization
	Cost differentials
	Physician productivity tracking
	Decreased length of stay
	Readmission rates
	Study sources of variability
	Increase revenue
	High risk patients
	Episodic care
	Pharmaceuticals-generics consumption
	GIS analysis

EXPLORATORY CODING SCHEME (Cont'd)	
CODES	**SUB-CODES**
USE OF DATA WAREHOUSING FOR MEDICAL PURPOSES	
USE OF DATA WAREHOUSING FOR CLINICAL PURPOSES	
USE OF DATA WAREHOUSING FOR RESEARCH PURPOSES	Medical-public health cohort discovery
	Clinical trials cohort discovery
	Applied research
	Retrospective research
	IRB review information
	IRB approved protocols
	Residents research
AREAS WITH MOST SIGNIFICANT RESULTS	Clinical use
	Quality improvement
	Research
	Increase revenue
	Healthcare reform
	Epidemiology
	Financial reporting
	Operations
AREAS LAGGING BEHIND	Phased-in delivery
	Lack of resources
	Users less data-driven
	Nursing use
IDENTICAL RESULTS WITHOUT DATA WAREHOUSING	Not achievable
	Achievable
	Other solutions
JUSTIFICATION OF DATA WAREHOUSING	Ease of manipulation
	Data laggtime
	Data integration
	Ease of understanding
	Data quality
	Users cohesion
	Accuracy
	Financial benefit
	Analyst work
	Data knowledge
	Actionable data
TOTAL: 25	**TOTAL: 150**

APPENDIX F: FRAMEWORK CODING SCHEME

FRAMEWORK CODING SCHEME	
CODES	**SUB-CODES**
USER NEEDS ASSESSMENTS	Initial assessment
	Post-design assessments
	No initial assessment
	Follow-up assessments
	Project-based
	No follow-up assessment
USER NEEDS MET	Initial user needs met
	Post user needs met
HOW TO EVALUATE COSTS	No financial evaluation
	Difficult to do
	Initial ROI
	Considered going forward
	Ongoing ROI
	Project-based
	Chargeback
	Budgeting
	TCO
	Initial cost-benefit analysis
HOW TO EVALUATE BENEFITS	No benefits evaluation
	Project-based
	Near real time analysis
	Improved turnaround time for data acquisition
	Number of requests for reports
	Number of dashboards
	Increased user base
	Scorecard
SUPPORT - TRAINING	Ad hoc training
	Initial training
	Unspecified training
	Train the trainers
SUPPORT - TECHNICAL SUPPORT	Ticketing system
	Helpdesk
	Help email
	Data stewards
SUPPORT - KNOWLEDGE SHARING	Users group meeting
	Listserve
	Sharepoint-Wiki
	Videos
	FAQs-Documentation
	Unspecified knowledge sharing
EVALUATION DIMENSIONS & FACTORS	Benefits
	Patient care delivery
	Financial impact
	Things impossible to do before
	Data harmonization
	Costs
	Source systems
	Support Mission
	Physical infrastructure
	System performance

FRAMEWORK CODING SCHEME (Cont'd)	
CODES	**SUB-CODES**
	Staff service
	Users needs
	Care continuum
	Sponsorship
	Customer Commitment
	HR management
	Users satisfaction
	Utilization
	Security
	Compliance w ith regulations
	Training
	Data Quality
	Governance
	Data latency
	Adoption rate
	Data completeness
	Data accuracy
	Single source of truth
	Users cohesion
	System Flexibility
EVALUATION METHODS	Customer surveys
	System monitoring
	Usage tracking
	Don't know
	Informal meetings
	Cost-benefit analysis
	ROI
	One-to-one record match
	Multiple methods
	Impact description
	Focus Group
	Interview s
	Correlation
	Leadership surveys
	External benchmarking
DATA QUALITY EVALUATION	Data custodians-stew ards
	Data Governance
	No data quality evaluation
	Users responsibility
	Quality framew ork
	Metadata
	Data profiling
	Metareport
	Data dictionaries
	Data model
DATA AVAILABILITY	Missing values
	Load statuses
DATA RELEVANCE	Users data needs
DATA RELIABILITY	Source systems dependency
	Source systems match
	ETL processes
	Defect tracking
	Business rules

FRAMEWORK CODING SCHEME (Cont'd)	
CODES	**SUB-CODES**
ARCHITECTURE EFFECTIVENESS	Build methodology
	Scalability
	Operation dashboard
FLEXIBILITY	External sources
INTEGRATION	XL-Access
	Data marts
	Data sources
	Governance
PERFORMANCE	Query reponse time
	Uptime
	Query response quality
	Criticality
	CPU usage
EARLY & ONGOING VALUE GENERATION	Collaborative approach
	Immediate use
	Time-bound delivery
	Concept definition
	Prototypes
	Build they will come
	BI tool first
	New functionalities
	Use cases prioritization
	Number of dashboard hits
	Developers usage
	Number of dashboards built
	Number of reports built
	Bridge theory
	Number of reports accessed
	Publication of data products
	Project-based
USAGE EVALUATION	Tracking methods
	Queries run
	Number of users
	Usability
	Reports usage
	Databases accessed
	Grants
	Usefulness
	Publications
	Dashboards usage
USER SATISFACTION-ISSUES AWARENESS	Users direct feedback
	Ticketing system
	No formal feedback
	Users group meeting
	Helpdesk
	Surveys
	Business partners
	Access issues
	Upper-level management
	During training
	Steering Committee
	System tracking
	Power users
TOTAL: 17	**TOTAL: 142**

APPENDIX G: EXPLANATORY CODING SCHEME

EXPLANATORY CODING SCHEME	
CODES	**SUB-CODES**
TOPIC NOT ADDRESSED	What benefits are vs. how to evaluate them
	Steering committee vs. evaluating
	Who the users are vs. how to assess who they are
	Being successful vs. user needs met
	How flexible the architecture is vs. how to evaluate flexibility
	How data is integrated vs. how to evaluate integration
LACK OF PRECISE MEASURES	Unknown number of users
	Unknown FTE count
	Unknown financial impact
	Unknown budget
	Unknown number of requests
	Unknown time saved
	Unknown data quality confidence
	Unknown satisfaction survey schedule
	Unknown usage
TO WARD OFF PROBLEMS	
CONSULTING FIRMS ENGAGEMENTS	Methodology
	Initial user needs assessments
	Ongoing engagement
EVOLVING NATURE OF HEALTH DATA WAREHOUSING	
REVENUE GENERATING REPORTS	
ANECDOTAL EVIDENCE	
MONITORING SUCCESS VS. EVALUATION	
RECOGNITION VS. EVALUATION	
PERCEIVED VALUE VS. EVALUATION	
NOT ASKED FOR	
NO CONCERN/COMPLAINT	
CONSIDERED GOING FORWARD	
IMPROVEMENT NEEDED	
TOTAL: 14	**TOTAL: 18**