The Use of Data Warehousing to Support Decision Making

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1. Introduction

Decision-making is an important aspect of management activity and many organizations use computers to support decision tasks. High quality decisions are expected to lead to more productive actions, quicker problem-solving, and better organizational performance. However, decisionmaking with computers within an organization may not be an easy task, particularly where the underlying problem is complex and ill-structured, or people experience information quality problems. To make high quality decisions, it seems crucial to have access to information that is as complete and relevant to decision tasks as possible[1], rather than just having an enormous volume of information. In practice, however, information may not be complete and relevant to decision tasks due to a variety of reasons such as missing (incomplete) data, irrelevant data, or inadequately defined or measured data. It is difficult to get high quality information pertinent to the decision at hand.

Organizations may find themselves bogged down by database management systems containing a large number of data errors. In addition, the task of fixing errors in database management systems is very difficult. Consequently, organizations where decision-makers experience information quality problems may end up taking unnecessary risks by accepting impractical ideas and making errors in interpretation, or ignoring important ideas[2]. Wang and Strong[3] noted that poor data quality can have substantial negative social and economic impacts. Based on a recent industry report, the economic and social damage from poor-quality information costs billions of dollars [4].

According to the literature, data is a prerequisite for information and information can be created from its raw data. The knowledge management literature describes distinctions among data, information, and knowledge. Tuomi[5, p. 103] states: "The generally accepted view sees data as simple facts that become information as they are combined into meaningful structures, which subsequently become knowledge as meaningful information is put into a context and when it can be used to make predictions." Similarly, according to Davenport and Prusak[6], data is a set of discrete, objective facts about events. According to

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Spek and Spijkervet[7], data are understood to be symbols that have not yet been interpreted, and information is data with meaning. Or, data are simple observations of states of the world, and information is data endowed with relevance and purpose[8]. According to Wiig[9], information consists of facts and data that are organized to describe a particular situation or condition. According to Spiegler[10], with elapsed time, database operations such as organize, sort, calculate, retrieve, and report are required to transform data to information.

In the IS literature, information quality is one of two major dimensions for evaluating the success of information systems[11,12] and decision quality is a function of information quality[1]. Graphical information representation research is of interest to many disciplines, such as Statistics, Psychology, Education, Engineering, Management, and Information Systems[13]. Traditionally, problem solvers have relied on graphical information representations in improving decision quality[14], because they make faster, more accurate decisIons when their information is presented in a format that best matches the characteristics of their task[15-18]. However, it is not well understood whether graphical data representations affect problem-solving performance in decision-making settings. Hence, it would be worth investigating the effect of representational data quality(DQ) on decision performance. The lack of research on the relationship between representational DQ and decision performance calls for a review of the relevant literature.

A data warehouse plays a role as a repository of integrated information, including various databases and legacy data sources[19]. According to Benander et al[19], the size of a data warehouse is usually massive and the data warehouse typically stores a wide range of information that has been generated over long periods of time. Accordingly, because of a huge amount of information in a data warehouse people may experience information overload. In addition, data in a data warehouse may vary in quality and relevance to decision tasks, which makes decision tasks difficult for decision-makers. However, there are not many studies whether data warehousing provides decision-makers with high quality representational data pertinent to the decision at hand. This lack of research on the relationship between data warehousing and representational DQ calls for research. Therefore, the research aim of this paper is to examine the underlying theoretical and empirical support thoroughly for the relationship between data warehousing and representational DQ and the relationship between representational DQ and decision performance.

2. Importance of Research

Increasing numbers of organizations across industries have adopted and planed to adopt data warehousing to support their DSS functions[20,21]. The Palo Alto Management Group predicts that the data warehousing market will reach up to $113.5 billion in 2005[22]. Given the significant and growing use of data warehousing to support organizational decision-making, the need for research in this area calls for thorough literature review and empirical studies.

In addition, the investigation of factors that can be tied to decision performance is important, since the factors will be useful as a basis for improving decision performance. Todd and Benbasat[13] provide a comprehensive literature review of the impact of IT on decision-making. Based on their literature review, the relationship between IT and decision-making is not well understood[23-25]. To further clarify the role of various moderating and mediating variables that influence decision performance, researchers investigated decision-maker capability in the context of DSS[27] and in the context of experts or knowledge-based systems[28-30], and the key mediating processes related to decision strategy in the context of DSS[31]. Despite many decision performance studies that examined these factors, the relationship between the factors and decision performance is still not well understood[26]. Since the relationship between these factors and decision-making is not well understood, rather than studying the direct effects of information technology on decision performance[23-25], or the effects of moderating and mediating variables, such as decision-maker capability[27-30] and decision strategy[31], on decision performance, the proposed study will review the effects of information technology (e.g., data warehousing) and representational data quality on decision performance. Explicit literature review of data warehousing and representational information may lead to the specification of influences on decision performance. That is, the proposed study will attempt to link a specific application (e.g., data warehouse) to the resulting decision-making through representational DQ, which is expected to strengthen the tenuous ties between information technology issues and decision-making. This area of study is expected to extend a body of research examining the effects of IT on human decision-making performance.

3. Data Warehousing

Watson et al.[32] conducted a descriptive study by using a survey to learn about current practices in data warehousing. One hundred and six data warehousing managers and professionals provided data about their companies' data warehousing experiences. The findings provided interesting and valuable insights into current data warehousing practices, especially the benefits of data warehousing. Some of the findings are: data warehousing is primarily the domain of large firms, but even smaller ones have a data warehousing initiative. Data warehousing sponsorship usually comes from a business unit, and marketing and sales is the most common driver behind a data warehousing initiative. They also found that there is no dominant architecture for data warehousing. Most importantly for the proposed study, they pointed out that the greatest realized benefit from data warehousing is "more and better data."

To provide better data, various information systems are making possible the access of data across a firm and among a firm's business partners. In recent years, data warehousing and the Internet are considered as the two key technologies that offer potential solutions for managing corporate data[33]. Data warehousing delivers data and the Internet makes it easy and less costly to access data from anywhere at anytime. Therefore, the integration of the two technologies makes the processing and distributing of important data and information more efficient and economical. In addition, the integration of these two technologies leads to Web-based data warehousing. Due to the explosive development in the data warehousing and Web-related technology available today, Web-based data warehousing is expected to gain more and more attention among organizations.

Emerging technologies integrated with data warehousing offer competitive advantages to organizations. New forms of data are being integrated

(Table 1) Operational Databases vs. Warehouse Databases (Benander et al., 2000)

Characteristic	Operational Databases	Warehouse Databases
Users	All users	Executives, analysts, customer service representatives
Goal	Record keeping (OLTP: Online Transaction Processing)	Information analysis (OLAP: Online Analysis Processing, etc.), decision support, database marketing
Update	Online	Batch
Query Level	Atomic, detailed	Aggregated, summarized, integrated
Time Horizon	Mainly present	Historical + present + future
Data Source	Internal	Internal + external
Orientation	Entity oriented (product, account, customer…)	Category oriented (product type, account type, customer segment…)
Data Volumes	Gigabytes	Gigabytes/terabytes
Process	Transaction driven	Analysis driven
Structure	Relatively static	Dynamic

with data warehouses to provide high quality representational data to decision makers. According to Benander et al.[19], large blocks of text, pictures, graphics, and even sound are being added to traditional data. Newly implemented data warehouses that include more varied complex data types require specialized database features. During the past several years, querying a database for text, color, or sound has become a reality. Because these characteristics and features of a new generation datawarehouse are in many ways very different than those of a typical database, they may be able to increase the quality of representational data.

Benander et al[19] presented the significant differences between an operational database and a data warehouse in Table 1. They differ not only in their ultimate purposes, but also in the types and amount of data stored in them and the methods by which they are populated, updated, and accessed. In addition, they explained that one of the significant differences between an operational database and a data warehouse is the way of re presenting data. In an operational database that has been designed using traditional inflexible relational database design principles, data is represented as tables. On the other hand, in a data warehouse, there are many instances where data is most naturally represented in a flexible form as multi-dimensional tables.

Benander et al[19] also pointed out the physical design differences between operational databases and data warehouse databases. According to them, an important goal for an operational database is to provide fast update and query transactions. The physical structure of an operational database is designed to ensure update efficiency and data integrity over small sets of related data. On the other hand, data warehouses are typically used to answer analytic questions in a user-friendly, ad hoc query environment. The physical structure of a data warehouse is designed to provide data loading and storage efficiency and fast ad hoc query response time. This structure difference may provide different accessibility data quality to decision-makers.

According to Gray and Watson[34], two unique characteristics of a data warehouse compared to an operational database are the length of the time horizon on the data it contains and the aggregated data in tables. Park[35] used these characteristics (the length of time horizon on data and aggregated data in tables) of a data warehouse as independent variables for his laboratory experiment to examine the effects of data warehousing on decision performance.

Park[35] conducted a laboratory experiment to examine the effects of data warehousing on decision performance. His study employed one dependent variable and two independent variables. The dependent variable was decision performance and the two independent variables were database characteristics and task complexity: three different DSS database characteristics (a traditional DSS database, DW with long-time history, and DW with long-time history and aggregated data) and two levels of task complexity (high and low). Thus, the experiment yielded a 2 X 3 factorial design. The result showed that the decision performance of DSS users supported with both long-time history and aggregated data was significantly higher than that for DSS users supported only with a traditional database. However, the performance of DSS users supported with both long-time history and aggregated data was not significantly different from that of data warehousing groups with long-time history only. Also, no significant difference was found between the traditional DSS group and the data warehousing group with long-time history only. Based on these findings, Park inferred that to improve decision performance of DSS users, a data warehouse must provide both long-time history and aggregated data. Rather than examining the length of time horizon on data and aggregated data, this study focuses on the fact that whether or not data warehousing provides high quality representational data, which may lead to increased problem-solving efficiency and effectiveness.

4. Representational Information

Tan and Benbasat[13, p. 417] state: "There is now common agreement in the Information Systems(IS) graphics research literature that the quality of a given representation depends on the characteristics of the task to which it is to be applied[15-18]." Vessey[36] also suggests that a decision-maker's task processing would be more efficientis, they enable a set of data points to be examined simultaneously, analytical processes are those used to both extract and act on discrete data values. Since symbolic tasks need precise data values, they are best accomplished using analytical processes.

The theory of cognitive fit focuses on the effect of a match between problem representation and task on problem-solving performance: spatial tasks need spatial representations; symbolic tasks need symbolic information. Specifically, while tables emphasize symbolic information and lead to better performance for the task of reading specific data values, graphs emphasize spatial information and lead to better performance for most elementary spatial tasks, including summarizing data, showing trends, comparing points and patterns, and showing deviations[17,36]. Previous research on the graphical representation of information developed a sound taxonomy for classifying tasks: elementary tasks or decision activities[37]. Elementary tasks include basic perceptual cognitive information processes (e.g., retrieval of a data value or comparison of two data values). On the other hand, decision activities in

(Table 2) Analysis of Paradigmatic Symbolic Information Acquisition Tasks (Vessey, 1991)

Study		Types of Questions	Dependent Variables	Results	
				Accuracy	Time
Point/value reading	Washburne (1927)	Symbolic	Accuracy	T > G	–
	Carter (1947)	Symbolic	Accuracy Time	T > G	T > G1
	Carter (1948)	Symbolic	Accuracy Time	T > G	T > G
	Power et al. (1984)	Symbolic	Accuracy Time	T > G	T > G
Point/value recall	Umanath et al. (1990)	Symbolic	Accuracy	T > G	–

[1]The 〉 sign for time means that performance is better, rather than time is greater. T=Table, G=Graph

clude higher mental processes such as judgment, integration of information, and inference (e.g., forecasting).

In sum, when high representational DQ is used (e.g., tables for symbolic tasks and decision activities or graphs for spatial and elementary tasks) to make decisions, problem-solving with cognitive fit results in increased problem-solving efficiency and effectiveness. However, when low representational DQ is used (e.g., graphs for symbolic tasks and decision activities or tables for spatial and elementary tasks), a mismatch happens between the problem representation and the task, which requires subjects to transform the data values derived from the problem representation into the mental representation suitable for task solution, which in turn has a negative impact on problem-solving performance. In Table 2, Vessey[36] summarized the results of several graphs versus tables representations studies investigating performance on symbolic tasks.

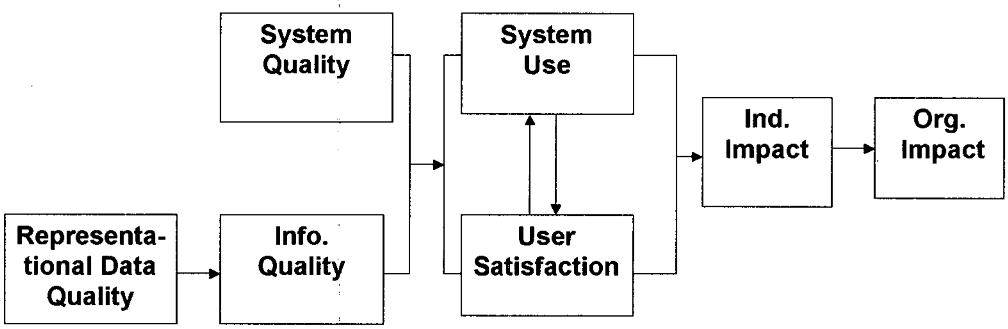
Chandra and Krovi[38] extended the theory of cognitive fit to account for the congruence between external representation (e.g., information organization) and internal representation, and tested their extended model in an experimental setting with the two models of external representation (prepositional networks model from the cognition literature and object-oriented model from the systems literature). Chandra and Krovi state[38, p. 273]: "While the cognitive fit is an excellent framework for understanding the relationship between problem representation and problem-solving task, *it does not explicitly account for specific internal representations* and their effect on the efficiency and effectiveness of information retrieval." The logic in their model is that if an already existing knowledge structure (internal representation) is congruent with information organization, the problem solver is better able to match the latter to the internal knowledge, thereby leading to the better efficiency and effectiveness of information retrieval performance. Overall findings of their study provide some evidence that the retrieval process benefits when information organization is congruent with internal representation.

Similarly, research in cognition and human information processing suggests that designing for comprehension is an effective way to reduce a reader's mental efforts to understand the contents of a document[39]. The nature of the information retrieval process is likely to differ from managerial problem-solving. However, if the system presents data necessary to solve problems in such a way that they are organized, interpretable, and easy to understand (e.g., high-quality representational data), it would create a congruence between external (information organization) and internal representation. As such, it could be possible to infer that problem-solving performance can be improved due to the congruence leading to the better efficiency and effectiveness of retrieval process for the information necessary to make decisions.

5. Conclusions And Discussion

When high representational DQ is used to solve the tasks (e.g., tables for symbolic tasks and decision activities or graphs for spatial and elementary tasks) in the data warehouse environment, problem-solving with cognitive fit resultes in increased problem-solving efficiency and effectiveness. However, when low representational DQ is used (e.g., graphs for symbolic tasks and decision activities or tables for spatial and elementary tasks), a mismatch occurs between the problem representation and the tasks, which requires subjects to transform the data values derived from the problem representation into the mental representation suitable for task solution, which in turn has a negative impact on problem-solving performance. Therefore, it may be possible to infer that data warehouses that provides high quality representational data may influence problem-solving accuracy and time, thus confirming the cognitive fit theory.

In addition, this study may extend the IS success model[11,12]. Based on a review of knowledge management literature, this research assumed that data is a prerequisite for information and information can be created from its raw data. DeLone and McLean[11,12] postulated that system quality and information quality singularly and jointly affect both system use and user satisfaction that are direct antecedents of "individual impact." Thus, based on DeLone and McLean's model and the assumption mentioned above, this study predicts that improved representational data quality would positively affect information quality, which affects both system use and user satisfaction, which in turn have an impact on user performance. The thorough literature review of this study shows that the effects of representational DQ influences problem-solving efficiency and effectiveness. Thus, this study are partially consistent with the IS success model. However, what is lacking is a detailed model for



(Figure 1) IS Success Model with Representational Data Quality describing how data (quality) is transformed into information (quality), the strength of the relationship between data (quality) and information (quality), and the strength of the relationship be tween information (quality), once transformed, and user performance. One area for future research would be to develop a model examining the transformation of data (quality) into information (quality). Figure 2 presents a model for extending the IS success model by recognizing and including the representational aspect of data quality into the model.

The reviewed main effects of representational DQ on problem-solving performance within the data warehouse environment has practical implications for enhancing the efficiency and effectiveness of problem-solving. In order to improve users' ability to make decisions, systems designers and managers should not only make data available to users, but also enable users to access better (high-quality) representational data. To accomplish this, it is recommended that systems designers and managers support the task by providing users with high-quality representational data that matches the task. Large database management systems such as data warehouses have continued to be well ingrained into the business environment as one of the most important strategic initiatives in the information systems field[40] and a dedicated source of data to support decision-making applications[34]. As organizations increasingly adopt distributed repositories such as data warehouses, it seems clear that various kinds of valuable information can be dispersed across the information systems in an organization. Strong et al[41] also found some data quality problems caused by integrating data across distributed systems. Thus, in order to enable users access high-quality data, systems designers, builders, and database administrators should ensure the integrity of data in such distributed data warehouses.

In addition, by understanding the effects of representational DQ on problem-solving performance, corresponding design and/or functional features of data warehousing can be identified and implemented as valuable mechanisms to practitioners to solve problems more efficiently and effectively. For example, according to Strong et al[41], representational DQ includes concerns about how well data matches task contexts because decision makers in practice evaluate representational DQ relative to their tasks. Decision makers in practice perform many different tasks and frequently face complex decisions. In addition, the information necessary to make decisions varies among organizations and tasks. Since the information requirements for many different tasks change, representational DQ that matches task context will also change over time. Thus, Strong et al[41] recommend flexible systems with data that can be easily aggregated and manipulated in tables. Wixom and Watson[42] also asserted that data warehouses must contain high-quality data, flexibly respond to users' requests for data, and integrate data in the ways that are required by users, all in order to create value for organIzations.

Finally, the findings of this study may help organizations to justify their attempt of improving data quality and/or their investments in a certain information technology. Based on a recent industry report, a data warehouse provides the repository of data used for decision support [40] and a data warehousing project is a quite expensive undertaking. According to Watson and Haley[20], the typical project costs over $1 million in the first year alone. Many organizations expect that a data warehouse as a dedicated source of information[34] will provide high quality information, which leads to the improvement of decision performance. Since few empirical studies of the impact of representational data quality on decision-making performance within the data warehouse environment have been investigated in the IS literature, many organizations might have made investments in expensive data warehouse projects without theoretical foundation. Since this study explained that data quality, especially representational DQ, brought problem-solving effectiveness and efficiency improvements, improving reprsentational data quality by investing in data management practices would appear to be beneficial for organizations' performance. Thus, this study based on the literature review may provide evidence that helps organizations to justify their efforts to improve representational data quality. Because a single literature review study is not sufficient to validate the findings, further empirical research should address this limitation and apply the findings of this study in specific contexts, population, and decision support technology as a whole.

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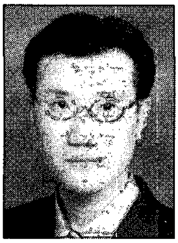

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