정보 시각화 형태와 정황 추론에 의한 인식 처리에 관한 연구

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Cognitive Processing with Information Visualization Types and Contextual Reasoning

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Abstract

The effects of information quality and the importance of information have been reported in the Information Systems (IS) literature. However, little has been learned about the impact of information visualization types and contextual information on decision quality. Therefore, this study investigated the interaction effects of these variables on decision quality by conducting a laboratory experiment. Based on two types of information visualization and the availableness of contextual information, this study had a 2x2 factorial design. The dependent variables used to measure the outcomes of decision quality were decision accuracy and time. The results demonstrated that the effects of contextual information on decision quality were significant. In addition, there was a significant main effect of information visualization on decision accuracy. The findings suggest that decision makers can expect to improve their decision quality by enhancing information visualization types and contextual information. This research may extend a body of research examining the effects of factors that can be tied to human decision-making performance.

Keywords : Information Visualization, Contextual Information, Decision Quality

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1. INTRODUCTION

Since the beginning of the computer age, IS researchers have addressed the issue of information characteristics. They have investigated various information characteristics to measure the value of information and the impact of information on decision quality. Gallaher [1974] used several information characteristic items to measure the value of a group of IS reports. The items included relevance, informativeness, usefulness, and importance. Ahituv [1980] used five information characteristics to measure information value : accuracy, timeliness, relevance, aggregation, and formatting. To develop a composite measure of information value, King and Epstein [1983] used various information attributes such as sufficiency, understandability, freedom from bias, reliability, decision relevance, comparability, and quantitativeness. Iivari and Koskela [1987] used various information characteristic criteria to measure users' information satisfaction. Their items included relevance, comprehensiveness, recentness, accuracy, credibility, convenience, timeliness, interpretability, and adaptability.

Besides the various information characteristics and attributes listed above, IS researchers also have paid attention to information's visualization and context. Wang and Strong [1996] defined contextual data as data that can add value because it is relevant, timely, complete, and appropriate in terms of amount. Yet, for the data to be considered of good visual representation, the system must present the data in such a way that it is interpretable, easy to understand, and represented concisely and consistently [Wang and Strong, 1996]. While graphical information visualization research is of interest to many disciplines, such as Statistics, Psychology, Education, Engineering, Management, and Information Systems [Tan and Benbasat, 1990], contextual information research has been the focus of attention in much information retrieval (IR) work [Brown and Jones, 2001; 2002; Dourish et al., 1993] and the Semantic Web.

Many organizations use various information provided by information technologies and systems to make high quality decisions. High quality decisions are expected to lead to more productive actions, quicker problem-solving, and better organizational performance. However, decision-making with various information within an organization may not be an easy task, particularly where people experience information visualization problems and the lack of contextual information. To make better decisions, it seems crucial to have access to information that is as interpretable, easy to understand, and represented concisely and consistently as possible, rather than just having an enormous volume of information. In addition, decision makers should have access to information that is as complete and relevant to decision tasks as possible [Stephenson, 1985]. In practice, however, it is often difficult to get such high-quality information. That is, information may not be interpretable, easy to understand, nor represented concisely and consistently due to a variety of reasons such as poor data formats, missing (incomplete) data, irrelevant data, or inadequately defined data.

Furthermore, because of a huge amount of information in an organization, information may vary in quality, which makes decision tasks more difficult for decision-makers. Accordingly, people in an organization may find themselves bogged down by low-quality information. Consequently, organizations where people experience low-quality information problems, information visualization problems, and the lack of contextual information may end up taking unnecessary risks by accepting impractical ideas and making errors in interpretation, or ignoring important ideas. Based on a recent industry report, the economic and social damage from various information problems costs billions of dollars [Redman, 1998].

The investigation of factors that can be tied to decision-making is important, since the factors will be useful as a basis for improving decision quality. Todd and Benbasat [2000] provided 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 [Benbasat et al., 1993; Eierman et al., 1995; Sharda et al., 1988]. To further clarify the role of various moderating and mediating variables that influence decision-making, researchers investigated decision-maker capability in the context of DSS [Benbasat and Taylor, 1982] and in the context of experts or knowledge-based systems [Dhaliwal and Benbasat, 1996; Gregor and Benbasat, 1999; Nah et al., 1999], and the key mediating processes related to decision strategy in the context of DSS [Silver, 1990]. Despite many decision studies that examined these factors, the relationship between the factors and decision-making is still not well understood [Todd and Benbasat, 2000].

Since the relationship between these factors and decision-making is not well understood, rather than studying the direct effects of information technology and/or systems on decision quality [Benbasat et al., 1993; Eierman et al., 1995; Sharda et al., 1988], or the effects of moderating and mediating variables, such as decision-maker capability [Benbasat and Taylor, 1982; Dhaliwal and Benbasat, 1996; Gregor and Benbasat, 1999; Nah et al., 1999] and decision strategy [Silver, 1990], on decision-making, this study examined the interaction effects of different information visualization types and contextual information on decision quality.

In fact, the importance of information and the effects of various information characteristics have been studied in IS literature. However, little empirical evidence and understanding of the interaction effects of information visualization types and contextual information that can be tied to decision-making have been documented. Specifically, much of the information visualization research did not manipulate contextual information, nor did it show performance differences between individuals based on contextual information. Hence, it would be worth investigating the interaction effects of information visualization types and contextual information on decision quality. Thus, the goal of this research is to examine empirically the interaction effects of information visualization types and contextual information on decision quality. This area of study is focused on extending a body of research examining not only the effects of factors that can be tied to human decision-making, but also the predictions of information usages.

The remainder of this study is organized as follows. In Section 2, literature review and hypotheses are presented in detail. Section 3 describes the research methodology adopted for this study. In section 4, the results and findings are discussed. Finally, section 5 and 6 discusses and concludes the study.

2. LITERATURE REVIEW AND HYPOTHESES

2.1 Information Visualization

Information visualization research is of interest to many disciplines. The widely accepted view in the literature is that information in the form of pictures, graphs, or tables is generally regarded as superior in terms of the meaning of information (e.g., the ease of understanding and interpretability) to that in a thousand words [Benbasat and Dexter, 1985; DeSanctis, 1984; Javenpaa and Dickson, 1988; Jarvenpaa, Dickson, and DeSanctis, 1985; Vessey, 1991]. Hence, traditionally, decision makers have relied on graphical or tabular visualizations in improving decision quality [Smelcer and Carmel, 1997]. However, when the focus of information visualization research is taken on the comparison between graphical and tabular visualizations, then there have been largely equivocal results in the prior research. While some research found that graphical presentations are superior to tabular presentations [Benbasat and Schroeder, 1977; Lucas, 1981] for decision-making, some research found the opposite [Ghani and Lusk, 1981]. Addo [1989] considered the lack of theoretical basis and differences in measurements between studies as two primary reasons for the conflicting results. Specifically, prior studies used different definition and measurement of task type or complexities. Frownfelter-Lohrke [1998] provided a comprehensive literature review of additional reasons for the conflicting results, such as use of poor graphical formats, content differences between graphical and tabular formats, uncontrolled task effects, omitted correlated variables, uncontrolled learning effects, differing or unobjective measures of decision quality, and univariate tests of related dependent variables [Hard and Vanecek, 1991; Benbasat et al., 1986; DeSanctis, 1984].

In regard of the mixed results, Tan and Benbasat [1990, p. 417] stated: "There is now common agreement in the Information Systems (IS) graphics research literature that the quality of a given information representation depends on the characteristics of the task to which it is to be applied [DeSanctis, 1984; Jarvenpaa et al., 1985; Benbasat and Dexter, 1985, 1986; Javenpaa and Dickson, 1988]." Vessey [1991] also suggested that a decision-maker's task processing would be more efficient and effective when there is a cognitive fit (match) between the information emphasized in the visualization type and that required by the task type. That is, the theory of cognitive fit focuses on the effect of a match between information visualization and task on decision-making performance : spatial tasks need spatial information; symbolic tasks need symbolic information. More 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 [Jarvenpaa and Dickson, 1988; Vessay, 1991].

The theory of cognitive fit is a useful perspective to understand how and when different information visualizations are useful in supporting task strategies (methods or processes) required to perform a task. The three fundamental aspects addressed in the theory are: (1) the information visualization (graphs and tables), (2) the decision-making task (spatial and symbolic), and (3) the processes or strategies decision makers use (perceptual and analytical). According to the theory, when there is a complete fit of information visualization, processes, and task type, each visualization (e.g., graphs or tables) will lead to both quicker and more accurate decision-making by formulating a mental representation. That means, while perceptual processes view data values in context; that is, 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.

Chandra and Krovi [1999] extended the theory of cognitive fit to account for the congruence between external visualization (e.g., information organization) and internal visualization, and tested their extended model in an experimental setting with the two models of external visualization (prepositional networks model from the cognition literature and object-oriented model from the systems literature]. Chandra and Krovi stated [1999, p. 273] : "While the cognitive fit is an excellent framework for understanding the relationship between problem representation and decision-making 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 visualization) is congruent with information organization, the decision maker 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 visualization.

The nature of the information retrieval process is likely to differ from managerial decision-making. However, if the system presents information necessary to make decisions in such a way that they are organized, interpretable, easy to understand, and represented concisely and consistently, it would create a congruence between external and internal visualization. As such, it could be possible to infer that decision quality can be improved due to the congruence leading to the better efficiency and effectiveness of retrieval process for the information necessary to make decisions. Similarly, research in cognition and human information processing suggested that designing for comprehension is an effective way to reduce a reader's mental efforts to understand the contents of a document [Thuring et al., 1995].

Based on the discussion above, the following hypotheses are proposed.

H1 : Regardless of the use of contextual information, tabular visualization has more significant effect on decision time than graphical visualization for a symbolic task.

H1a : When decision makers use contextual information, tabular visualization has more significant effect on decision time than graphical visualization for a symbolic task.

H1b : When decision makers do not use contextual information, tabular visualization has more significant effect on decision time than graphical visualization for a symbolic task.

H2 : Regardless of the use of contextual information, tabular visualization has more significant effect on decision accuracy than graphical visualization for a symbolic task.

H2a : When decision makers use contextual information, tabular visualization has more significant effect on decision accuracy than graphical visualization for a symbolic task.

H2b : When decision makers do not use contextual information, tabular visualization has more significant effect on decision accuracy than graphical visualization for a symbolic task.

2.2 Contextual Information

Sharps [2003] asserted that if context information does not exist in working memory during decision cosideration, decision makers rely on a stlye of cognitive processing that may result in inaccurate decision making. Some researchers demonstrated this effect and addressed the importance of context information in decision making [Sharps et al., 2007]. In addition, Context information is most useful for not only information retrieval (IR) functions [Brown and Jones, 2001; 2002], but also browsing tasks [Dourish et al., 1993; Park and Kim, 2000]. IR systems are concerned with the finding of information, often in the form of text documents [Brown and Jones, 2001]. According to Brown and Jones, at one time, IR systems were almost exclusively the domain of the librarian. However, the advent of the World Wide Web (WWW) has changed this situation radically, and many people are now familiar with the use of IR systems in the form of web search engines.

Recently, the Semantic Web, which is the advanced form of IR systems, has been received strong attention because of its potential to increase the speed with which information can be found, integrated, aggregated, and analyzed. The Semantic Web is relevant to knowledge management and designed to provide decision makers with intelligent search for the information they need. Because the Semantic Web can answer a question or perform a search, decision makers can make more high-quality decisions. One of problems for an extension of the Semantic Web technologies is that the Semantic Web technologies and its applications cannot work properly without contextual information. Brown and Jones [2002] asserted that the use of context information leads to improvements in precision and retrieval speed. Jul and Furnas [1997] also asserted that context information plays an important role for effective information retrieval because each retrieval process takes place in a particular information environment and is tied to the specificity of the environment.

Dourish et al. [1993] studied two information systems, one paper based and one electronic, managing similar information within the same organization. In addition to the fact that the availability of contextual information makes browsing much more productive [Dourish et al., 1993; Park and Kim, 2000], they also found that information retrieved from these systems is interpreted subjectively by individuals. They pointed to contextual information contributing to this interpretation; that is, they addressed the importance of contextual information, which causes the same information to be interpreted in different ways once retrieved. Since this interpretation is critical in decision-making, it must be perceived to be correct and pertinent if information is to be of use to an individual. Thus, they emphasized that contextual information acts as a resource in the process of interpreting the information.

According to Wang and Strong [1996], data quality must be considered within the context of the task at hand; that is, data must be relevant, timely, complete, and appropriate in terms of amount so as to add value. To examine contextual data quality problems in practice, Strong et al. [1997] studied 42 data quality projects from three data-rich organizations: GoldenAir, an international airline; BetterCare, a hospital; and HyCare, a Health Maintenance Organization (HMO). They employed qualitative data collection and analysis techniques and collected data via interviews of data producers, consumers, and managers. They found three underlying causes for data consumers' complaints that available data does not support their tasks: missing data, inadequately defined or measured data, and data that could not be appropriately aggregated.

Strong et al. [1997] addressed the issue of incomplete data due to operational problems and design. They found that while GoldenAir's inventory data was incomplete due to operational problems, BetterCare's data was incomplete by systems design. For example, at GoldenAir, mechanics sometimes failed to record part numbers on their work activity forms. Because transaction data was incomplete, the inventory database could not be updated, which in turn produced inaccurate records. However, they observed that this was tolerated because the primary job of mechanics is to service aircraft in a timely manner, not to fill out forms. They also found that because of systems design, the amount of data in BetterCare's database is small enough to be accessible, but complete enough to be relevant and add value to data consumer's tasks. As a result, they observed that data consumers occasionally complained about incomplete data.

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. [1997] also found some contextual data quality problems caused by integrating data across distributed systems. At HyCare, data consumers complained about inconsistent definition and irrelevant data. They pointed out that these problems were caused by autonomous design decisions in each division. As a result, decision makers experienced information overload and difficulties in retrieving valuable information through these distributed systems.

In conclusion, based on these views, it could be possible to infer that decision-makers can benefit from contextual information because it can increase the efficiency and effectiveness of browsing and retrieval processes, as well as information interpretation processes [Brown and Jones, 2001; Dourish et al., 1993; Jul and Furnas, 1997; Park and Kim, 2000]. That is, if the system provides contextual information, then decision quality may be improved due to the improved efficiency and effectiveness of browsing, retrieval, and interpretation processes for the information necessary to make decisions.

Based on the discussion above, the following hypotheses are proposed.

H3 : Regardless of the types of information visualization, decision-making with contextual information will be faster than decision-making without contextual information for a symbolic task.

H3a : If information is provided in the form of tabular visualization, decision-making with contextual information will be faster than decision-making without contextual information for a symbolic task.

H3b : If information is provided in the form of graphical visualization, decision-making with contextual information will be faster than decision-making without contextual information for a symbolic task.

H4 : Regardless of the types of information visualization, decision-making with contextual information will be more accurate than decision-making without contextual information for a symbolic task.

H4a : If information is provided in the form of tabular visualization, decision-making with contextual information will be more accurate than decision-making without contextual information for a symbolic task.

H4b : If information is provided in the form of graphical visualization, decision-making with contextual information will be more accurate than decision-making without contextual information for a symbolic task.

3. RESEARCH METHODOLOGY

3.1 Experimental Design and Procedures

Since a laboratory environment provides the control necessary to understand the effects of different information visualizations and contextual information on decision quality, a laboratory experiment was conducted. For the experiment, two types of information visualization (e.g., tabular vs. graphical) were given to subjects. Contextual information was given to only half of subjects. That is, based on the two factors, information visualization types (tabular vs. graphical) and contextual information (availability vs. unavailability), a 2 × 2 factorial design was implemented to test the hypotheses.

Because different groups of subjects used information in the different combinations of information visualization types and contextual information, decision quality was expected to vary depending on the combinations of information visualization types and contextual information. Each subject's decision quality was assessed based on predetermined measurement, and decision quality referred to decision time and the accuracy of decision-making that most accomplished the objective for the decision task. Thus, the purpose of the experiment to identify the effects of different information visualization types and contextual information on decision quality could be achieved.

A Web-based system to deliver a set of information in different visualization types and contextual information to the subjects was developed using the latest version of Web programming languages, Hyper Text Markup Language (HTML) and Practical Extraction and Report Language (PERL). The system developed for this experiment can be viewed as a surrogate of the database management systems such as data warehouses that are being used in various functional areas in industry because the subjects accessed information through this system.

Subjects participating in the experiment were undergraduate students. The experimental task for this study asked subjects to solve a decision problem. The decision task created by Jarvenpaa [2003] was used for this experiment, with some minor adjustments. It asks subjects to select a site for the construction of a restaurant. The information set given to the subjects was fit for the decision task and delivered to them by the system. The subjects were assigned randomly to one of the four treatments. In order to help subjects understand the decision-making rules for the task, an example to simulate the decision-making rules was provided. After that, the subjects were provided with an answer sheet to record their solutions as they performed the task. Next, with the information set and the task, the subjects made decisions. Finally, this study observed the effects of the various treatments on decision quality.

3.2 Independent Variables

The first independent variable is two different types of information visualization. Previous information visualization research developed a sound taxonomy for classifying tasks: elementary tasks or decision activities [Newell and Simon, 1972]. The decision task used here, with known solutions, was close to decision activities rather than elementary tasks in terms of difficulty, requiring higher mental processes and managerial analysis such as judgment, integration of information, and inference. The experiment used two different types of information visualization, referred to as tabular and graphical visualizations. That is, two attributes of information visualization (e.g., tabular and graphical) were used to map to the main information types. While a table presents information as a series of discrete numbers, a graph presents information as a series of colors or patterns [Vessey, 1991]. This study carefully constructed the tabular and graphical visualizations to contain the same information. In other words, the two types of information visualization provided equivalent values, except in the information visualization formats. Since the experimental decision-making task for this study was close to decision activities rather than elementary or spatial tasks, based on the theory of cognitive fit [Vessey, 1991], it was believed that there was a cognitive fit between information in the form of tabular visualization and the experimental decision-making task. Thus, tabular visualization was expected to facilitate the task' solution and to produce superior performance than graphical visualization.

Attaining high-quality contextual information is a research challenge [Madnick, 1995; Strong et al., 1997], because tasks and their contexts vary across time and information consumers [Wang and Strong, 1996]. As mentioned above, Strong et al. [1997] found three main causes in general for information consumers' complaints that available information does not support their tasks: missing [incomplete] data, inadequately defined or measured data, and data that could not be appropriately aggregated. Based on their findings, it seems possible to infer that providing information consumers with relevant, complete, and aggregated data may add value to the tasks of information consumers and may be one of the ways to solve the contextual information problems.

The second independent variable is contextual information. The subjects supported with an appropriate amount of relevant, complete, and aggregated data were considered as being assigned to the experimental treatment of contextual information availability. On the other hand, the subjects considered as being assigned to the treatment of contextual information unavailability was given a limited amount of contextual data. That is, no aggregated data was given to the subjects. In addition, they used irrelevant and incomplete data. For example, a couple of numbers in the information set given to the subjects was missing. Therefore, the subjects had to go through extra steps to infer the information necessary to make decisions.

3.3 Dependent Variables

The dependent variable of this study is decision quality. Decision quality was operationalized as the accuracy of decision-making and decision time. Decision-making accuracy was measured by the number of correct answers from the correct solutions. That is, decision-making accuracy was measured by dividing the number of correct answers by the number of total problems and expressing the result as a percent of the correct solution.

This study measured decision time as the total time in seconds the subjects required to select the best site from the candidates. That is, decision time was measured from the time when the subjects began working on the task until they recorded their solutions on their answer sheet and logged out of the system. Fisher et al. [2003] distinguished between time constraints and time pressure. According to them, a time constraint is a specific allotment of time for making a decision, while time pressure is a subjective reaction to the amount of time allotted. Researchers found some mixed results with respect to the effects of time pressure on decision-making. Time pressure decreases decision accuracy [Zakay and Wooler, 1984] and can impair the performance of some decision makers more than others [Ahituv et al., 1998]. On the other hand, Austin [2001] found that increasing time pressure may increase quality in software development projects. According to Dukerich and Nichols [1991], time constraints may have more impact on decision-making for novices than for sophisticated decision-makers. Because time factors, pressure or constraints, affect decision-making, subjects were not informed of any time expectation for this experiment.

4. RESEARCH FINDINGS

A total of 40 undergraduate students participated in the experiment. Decision accuracy and time were each analyzed with two-way ANOVAs. The tests were carried out at a 95% confidence level. The descriptive statistics for the dependent variables are summarized in <Table 1>.

The results of the two-way ANOVA for time showed that the main effects of information visualization ($p = .044$) and contextual information ($p = .000$) on decision time were significant (see <Table 2>). However, since the main effect of information visualization on time was barely significant, one-way ANOVA was performed for this variable. The one-way ANOVA for time showed no significant main effect of information visualization ($F = 1.734$, $p = .196$). The results indicated that regardless of the availability of contextual information, subjects using tabular visualization did not take less time than subjects using graphical visualization. That means, decision-making with tabular visualization was not significantly shorter than decision- making with graphical

〈Table 1〉 Descriptive Statistics for Decision Quality

Measures	Treatment Conditions			
	Tabular Visualization		Graphical Visualization	
	When contextual information was available	When contextual information was not available	When contextual information was available	When contextual information was not available
Decision Accuracy : (a higher score implies greater accuracy)				
Mean	95.00	69.63	55.25	23.12
Std. Dev.	9.3541	21.64	24.32	12.73
N	10	10	10	10
Decision Time : (minutes : seconds)				
Mean	22:22	33:18	25:12	36:29
Std. Dev.	6:35	03:15	04:21	03:10
n	10	10	10	10

〈Table 2〉 ANOVA Table for Two-Way Analysis of Decision Time : Information Visualization by Contextual Information

Source	Type III Sum of Squares	Mean Square	F	Sig.
Corrected Model	4766379.500(b)	1588793.167	21.200	.000
Intercept	123981452.100	123981452.100	1654.341	.000
Contextual Infor. Use	4439556.900	4439556.900	59.239	.000
VISUAL	325802.500	325802.500	4.347	.044
Context Infor. Use * VISUAL	1020.100	1020.100	.014	.908
Error	2697952.400	74943.122		
Total	131445784.000			
Corrected Total	7464331.900			

주) (a) R Squared = .639 (Adjusted R Squared = .608).

visualization for a symbolic task. Therefore, H1 was rejected. However, consistent with expectations, the task with contextual information was solved more quickly than the task without contextual information. Therefore, H3 was supported.

The ANOVA on decision accuracy found a significant main effect for information visualization (p = .000, see <Table 3>). Subjects using tabular visualization made more accurate decisions than subjects using graphical visualization. Therefore, H2 was supported. Also, the results of ANOVA for decision accuracy showed that there was a significant main effect of contextual information for decision accuracy (p = .000, see <Table 3>). Subjects completing the task with contextual information had superior decision accuracy to those completing the task without contextual information. Thus, H4 was also supported.

For decision time, the interaction between information visualization and contextual information was not significant (p = .908, see <Table 2>), indicating these two variables do

〈Table 3〉 ANOVA Table for Two-Way Analysis of Decision Accuracy : Information Visualization by Contextual Information

Source	Type III Sum of Squares	Mean Square	F	Sig.
Corrected Model	26977.188(b)	8992.396	27.463	.000
Intercept	147622.500	147622.500	450.839	.000
Contextual Infor. Use	8265.625	8265.625	25.243	.000
VISUAL	18597.656	18597.656	56.797	.000
Context Infor. Use * VISUAL	113.906	113.906	.348	.559
Error	11787.813	327.439		
Total	186387.500			
Corrected Total	38765.000			

주) (a) R Squared = .696 (Adjusted R Squared = .671).

not jointly affect decision time. <Table 1> shows that a comparison involving tabular and graphical visualizations in the effect of contextual information indicated no significant mean difference on decision time (p = .271, see <Table 4>). Therefore, H1a was rejected. This suggests that tabular visualization did not provide benefits to decision time in the effect of contextual information. That is, the subjects using graphical visualization with contextual information for the task apparently take only a small amount of additional time to translate the information in graph format into the precise numeric information it represents than the subjects using tabular visualization with contextual information. Based on these results, it could be possible to infer that the subjects using graphical visualization with contextual information did not spent most time primarily on translating the data presented in the graph into the precise numeric data. Instead, they might spent most time primarily on understanding and solving the decision task as the subjects using tabular visualization with contextual information did.

On the other hand, the effect of information visualization on decision time was significant when contextual information was not available (p = .041, see <Table 4>). Therefore, H1b was supported. When no contextual information was given, the subjects using the graphical visualization for the task took more time than the subjects using the tabular visualization for the task. This is likely due to the fact that when no contextual information was provided, the complexity of the task increases. That is, the subjects have to take additional effort to get the complete and relevant information by inferring and calculating activities with only the given incomplete and irrelevant information. In addition, the subjects using the graphical visualization try (as measured by time) not only to translate the graph information into the precise numeric information it represents to generate good solutions, but also to complete the task by understanding the task using the information they found at the previous step. In summary, it appears that the insignificant interaction effect between information visualization and contextual information resulted from the insignificant mean difference between tabular and graphical visualizations in the effect of contextual information, indicating these two variables do not jointly affect decision time.

For decision accuracy, the interaction between information visualization and contextual information was also not significant (p = .559, see <Table 3>), indicating these two variables do not jointly affect decision accuracy. It means that even though the main effects of information visualization and contextual information were each significant on decision accuracy, the interaction effect was not significant when these variables were used together simultaneously. <Table 4> presents the results of testing the hypotheses of this study.

〈Table 4〉 Summary of Hypotheses Testing

Hypotheses	Statistics		Evaluation
H1	F = 1.734	P = .196	Rejected
H1a	F = 1.289	P = .271	Rejected
H1b	F = 4.872	P = .041	Supported
H2	F = 35.042	P = .000	Supported
H2a	F = 23.267	P = .000	Supported
H2b	F = 34.286	P = .000	Supported
H3	F = 55.774	P = .000	Supported
H3a	F = 22.080	P = .000	Supported
H3b	F = 43.675	P = .000	Supported
H4	F = 10.298	P = .003	Supported
H4a	F = 11.582	P = .003	Supported
H4b	F = 13.690	P = .002	Supported

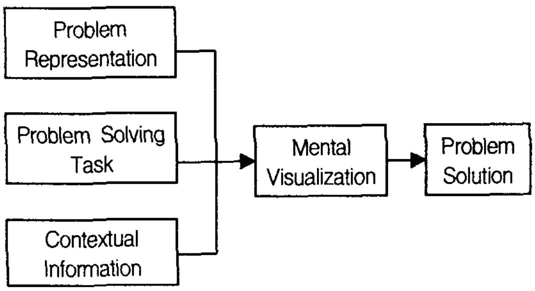
5. DISCUSSION

There was a significant main effect of contextual information on decision accuracy and time. In addition, there was a significant main effect of information visualization on decision accuracy. These results, especially the information visualization effect, are consistent with the theory of cognitive fit [Vessey, 1991] that was built upon a considerable amount of graphs versus tables visualizations studies. The task used in this study can be viewed as a symbolic task since it is best accomplished using precise information values. That is, subjects need discrete precise information values for carrying out accurate computations. The task used in this study does not involve the aspects of spatial task facilitated by the spatial properties of graphs, such as detecting trends over time or comparing patterns of variables. Therefore, it is hard to see the task used in this study as a spatial task. When tabular visualization was used in this experiment (e.g., symbolic task), decision-making with cognitive fit resulted in increased decision-making effectiveness. However, when graphical visualization was used for the task, a mismatch occurred between the information visualization and the task, which required subjects to transform the information values derived from the information visualization (e.g., graphs) into the mental visualization suitable for task solution, which in turn had a negative impact on decision-making effectiveness. Therefore, it seems clear that the results of this study, especially the main effect of information visualization on decision accuracy, are compatible with the cognitive fit theory.

As mentioned previously, contextual information was found to influence decision performance. In the effect of tabula visualization, the mean difference on decision accuracy between when contextual information was available (95.00) and when it was not available (69.63) was significant (F = 11.582, p = .003, see <Table 4>). This indicates that although there was a cognitive fit between information visualization (e.g., tables) and task type (e.g., symbolic task), the subjects produced more accurate outcomes when they used contextual information than when they did not use contextual information. In addition, in the effect of tabular visualization, the mean difference on decision time between when contextual information was available (22 : 22) and when it was not available (33 : 18) was also significant (F = 22.080, p = .000, see <Table 4>). That means, even though there is a cognitive fit between information visualization and task type, more time was required for the subjects without contextual information than the subjects with contextual information. As discussed before, these results may imply that if subjects used information in tabular visualization without contextual information, then the unavilableness of contextual information detrimentally affected decision-making by increasing cognitive complexity, which in turn had a negative impact on formulating a mental visualization, despite a fit between information visualization and task type. In other words, decision makers cannot use processes (and therefore cannot formulate mental visualizations) that require accurate and precise information.

According to the theory of cognitive fit, decision makers have to supply precise individual data values into the mental visualization suitable for task solution. However, when contextual informatioin is not available, the information given to the subjects contained incomplete and irrelevant data. In addition, no aggregated data was provided. Thus, even though the types of information emphasized in the decision-making elements (e.g., information visualization and task) match, incomplete and irrelevant information might hinder decision makers from furnishing accurate (precise) data into a mental visualization. Therefore, the interaction of contextual information with tabula visualization on decision-making accuracy and time that was observed in this study may demonstrate the importance of contextual information in the light of the cognitive fit theory.

In summary, based on the theory of cognitive fit and the analysis of decision-making outcomes, contextual information should be considered as an additional dimension to the domain of variables in the theory of cognitive fit (see <Figure 1>). However, since a single



〈Figure 1〉 Cognitive Fit with Contextual Information empirical study is not sufficient to validate this finding, additional research would be needed on the effect of contextual information on the formulation of a mental visualization.

The results of this study may have a practical implication for organizations to justify their attempt of improving decision quality and/or their investments in a certain information technology. A data warehouse provides the repository of information used for decision support [Watson, 2001] and a data warehousing project is a quite expensive undertaking. According to Watson and Haley [1997], 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 [Gray and Watson, 1989] will provide high quality information, which leads to the improvement of decision quality. Based on their expectations, many organizations might have made investments in such expensive data warehousing projects. Since the findings of this study showed that the use of information visualizations and contextual information brought decision effectiveness and efficiency improvements, having decision makers to use various information visualizations and contextual information by investing in database practices would improve decision quality and appear to be beneficial for organizations' performance. In other words, rather than providing users with information in fixed formats, some tools to convert information formats from tables to graphs or vice versa should be provided. Building such flexible information systems is necessary but not sufficient for information problems. Since incomplete (missing) and irrelevant data that exists across distributed systems in an organization triggers information problems [Strong et al., 1997], providing users with data access to easily update these incomplete and irrelevant data without database administrators' approval is required. This approach then may be able to solve contextual information problems due to incomplete and irrelevant data. That is, constant maintenance of database and systems (e.g., constant database updates) to meet changing data requirements is the best approach to provide high-quality information that matches with information consumers' tasks. In sum, this study may provide evidence that helps organizations to justify their efforts to improve decision quality.

Although this study provided a number of findings and conclusions that will be useful for improving our understanding of the impact of different information visualizations and contextual information on decision quality, it is subject to the limitations of laboratory research. Thus, a number of limitations should be considered in terms of the methods used when interpreting the findings. It is almost impossible to control the influence of all potential extraneous variances by the nature of the experimental setting, the subject population, the task type, and the set of information used in this study. For example, data were collected in different experimental sessions held in different computer laboratories. Although every effort was made to provide the subjects with the same instructions consistently on how to complete the task, it is possible that the subjects might not receive the same instructions due to different laboratory circumstances. Another example is that the subjects may have different cognitive abilities and cognitive styles. Thereby, a particular treatment group may have more introvert subjects than other groups or vice versa. However, it was believed that proper randomization was accomplished, the influences of those independent variables extraneous to the purposes of the study might be minimized or isolated.

Second, data were collected from a small sample of 40 students. Since the decision task used in this study is not so difficult for decision makers in practice, they were not considered as appropriate subjects. It is recommended that future study use more complicated decision tasks with practitioners. Since the subjects were undergraduate students, the findings of this study might not generalize to a broader population. In addition, there are hundreds of thousands of different platforms (PC, Macintosh, Unix etc.), different monitors, different browsers, and different versions of browsers. The website can look drastically different depending on which platform it is viewed. However, the experiment for this study cannot be conducted with every single platform and every single browser. This is an area of concern for external validity. External validity defines representativeness or generalizability and it is a difficult criterion to satisfy. When an experiment has been completed and a relation found, one should ask to what populations it could be generalized. This important scientific question should always be asked and answered. Because a single empirical study is not sufficient to validate the findings, further research should address these limitations (i.e., subject characteristics and experimental tools) and apply the findings of this study in specific contexts and decision support and data warehousing technology as a whole.

6. CONCLUSIONS

This study empirically investigated the interaction effects of different information visualizations and contextual information on decision quality by conducting a laboratory experiment. The results demonstrated that the effects of contextual information on decision-making effectiveness and efficiency are significant. In addition, there was a significant effect of information visualization on decision effectiveness. The findings provided empirical evidence to partially validate and extend the cognitive fit theory. Therefore, this study may be useful for informing the academic communities about the effects of information visualization types and contextual information. However, a number of limitations should be considered in terms of the methods used when interpreting the findings and future researchers would be wise to further examine and extend the findings of this study. Finally, it is postulated that despite these limitations, practitioners should be able to facilitate the design of database management systems such as data warehouses to improve their decision quality by enhancing the quality of information visualization types and contextual information in database management systems.

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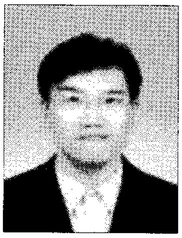
■ 저자소개



정 원 진

단국대학교 상경대학 경영학부에서 근무 중이며, University of Wisconsin - Milwaukee에서 경영정보학석사, Claremont Graduate University에서 경영정보학 박사학위를 받았다. 주요 관심분야는 데이터 품질, 데이터 웨어하우징, 의사결정지원 시스템, 지식정보 시스템, e-비즈니스 등이다.

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