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An Exploratory Study of Hypermedia Support for Problem Decomposition

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Abstract

Empirical hypermedia research has concentrated on usability rather than utility, and the research on utility has focused on information access as opposed to problem solving and decision making in organizations. This study, based on problem reduction theory, uses a hypermedia prototype system to support decision processes for solving a financial analysis problem. An exploratory laboratory experiment was conducted to study the feasibility of the prototype for hypermedia support of decision making. The process tracing techniques used suggest that a cognitive map of a decision maker's thought process may be constructed. Results offer a great deal of promise in the use of hypermedia for organizational decision support. The implications of this study for further research are discussed.

1. Introduction

Organizations are complex entities with many interrelated units and activities. Their information processing activities consist not only of information acquisition, storage, and retrieval, but also management of the relationships between sets of information and the models which operate on that information [17]. This information, including knowledge, may be well-structured or semi-structured and may exist in many forms and representations. The ultimate goal of information management is effective support of problem solving and decision making to meet organizational objectives.

The complexity of organizational problem solving often necessitates the use of strategies which decompose problems into sub-problems of more manageable size, then assimilate their individual solutions into an overall solution. In an already challenging environment involving large amounts of related information in varying forms, supporting organizational problem solving paradigms such as problem decomposition requires extraordinarily powerful and flexible information management techniques. The ability of hypermedia[1] to manage information chunks of many forms and media, and to relate them through multiple link types, makes it a promising candidate for organizational information management and may make it particularly valuable in supporting problem decomposition strategies.

Unfortunately, very little is known about the actual or potential contributions hypermedia may make in supporting problem decomposition. This is due to three factors. First, there are relatively few empirical studies of hypermedia, with the majority of those more concerned with simple usability rather than overall effectiveness and utility. Second, the overwhelming majority of hypermedia systems concentrate on support of information access rather than problem solving per se. Only a small number incorporate quantitative modeling and computational features. Finally, there is virtually no existing empirical research investigating hypermedia support of problem decomposition through decision process tracing methods.

The goal of the research project described in this paper is to remedy the lack of empirical investigation into how hypermedia may support problem decomposition approaches to problem solving in organizations. We do this not only by developing a framework for such investigation, but also by constructing an operational prototype incorporating many of the features necessary to conduct cognitive process tracing while users interact with a hypermedia system. Furthermore, we use the prototype in a pilot empirical study where subjects engage in problem solving activities using the system while process tracing facilities record their interaction with it. This provides "proof of concept," demonstrating the feasibility and value of hypermedia decision process tracing.

[1] In general, we will use the term hypermedia to encompass both hypertext and hypermedia without necessarily implying the existence of multimedia. Many of the cited works use hypertext or hypermedia with varying levels of distinction.

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2. Hypermedia Research Review

Three factors limit the contributions of existing hypermedia research to empirical issues of process tracing and problem solving using decomposition. First, most research has concentrated on usability rather than utility of the technology. While usability is important, utility is critical in supporting problem solving and decision making. Utility is "the question of whether the functionality of the system in principle can do what is needed" [29, p. 148]. Utility relates to other indicators of overall hypertext system acceptability as shown in Figure 1, reproduced from [28]. Hypertext utility is associated with many factors, including the quality of information contained in nodes, the usefulness of links between nodes, the navigational, access, and manipulation features of the user interface, and the suitability of the entire structure to the task at hand.

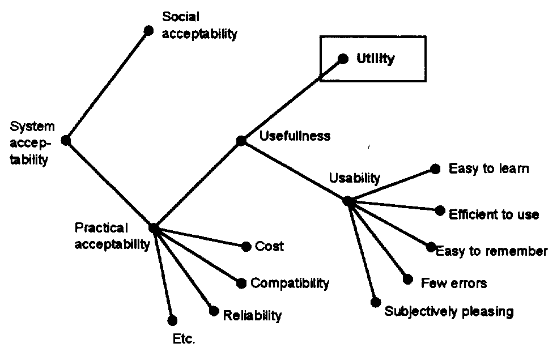

Figure 1: System acceptability parameters [28]

The second limiting factor of existing hypermedia research for our purposes is that even the usability research which has been performed is concerned predominantly with usage related to information access rather than problem solving. Support for this statement would ideally be found in a meta-analysis of hypermedia research--however the area of study is still relatively young for such work. One of the few examples [27] does not claim to be a detailed meta-analysis but rather a "broader analysis of the spectrum of issues related to hypertext usability." (p. 239). This study examined 92 usability issues over 30 published papers, dividing the usability issues into six general categories as summarized in Table 1.

The results of this survey show most independent variables to be technology related, with the majority of dependent variables related to relatively simple information access and retrieval tasks. Even conceptual prescriptions for usability research [27], [28] emphasize the information access and retrieval aspects of the technology, although some mention the value of visualizing information and structure in task-adaptive designs and helping users to deal with structural complexity [41]--the latter having direct applicability to decomposition approaches to problem solving. As we will discuss in Section 4, there are many more propositions, potentially testable hypotheses, and relevant variables which should be investigated.

The third limitation of existing hypermedia research as

Category	Example independent variables	Example dependent variables
Comparisons between various hardware devices.	CRTs vs. paper; screen size; use of color; use of pointing devices.	Reading times; error frequencies; time spent on medium and task; information access speed and patterns.
Various basic software aspects of the user interface.	Single vs. multiple windows; slow vs. fast response times	Time to locate and read text; time to complete tasks
Comparisons between hypertext and other computer systems.	Hypertext vs. scrolling text; hierarchical vs. linear text organization; hypertext vs. menus, commands, and expert systems.	Time to answer questions about text; concept recall; user subjective preference; node visitation frequency and patterns; problem solving time and proportion correct..
Comparisons between hypertext and printed paper.	Various on-line systems versus printed matter.	Various information retrieval and subjective measures.
Various hypertext facilities.	Presence of overview maps; button types; node size; link types.	Information access times and accuracy; user understandability of facility.
Effect of the task and individual user differences.	Task type; user age; user experience; user motivation.	Choice of navigation mechanisms; usage rates; task time.

Table 1: Hypertext usability research review, adapted and summarized from [27]

it concerns the present investigation is the lack of attention to systematic process tracing methods of the nature and level of sophistication typically found in the social sciences (where a significant body of research deals with eye-movement tracing, verbal protocol analysis, and other process tracing methods). Process tracing methods in decision support systems, including computer logging, have been proposed [39], but with the exception of [25], have not been studied in the context of hypermedia.

Several methods were used to locate previous empirical hypermedia research related to problem solving, problem decomposition, and hypermedia process tracing. A periodically updated hypertext/hypermedia bibliography [22], containing some 876 entries and available in machine-readable form, was electronically searched using keywords including decomposition, drill down, empirical, experiment, logging, problem reduction, problem solving, tracing, and usability. The index of a second hypertext/hypermedia bibliography [19] was examined in an attempt to locate additional empirical research in the same topic areas. Our literature review clearly indicates a paucity of empirical hypermedia research in the target areas, with the following examples representative of work at least falling in related areas. Empirical studies have examined authoring and browsing speed for novice users in an information storage and retrieval context [7], effects of hardware technologies [11], [18], [31], [32], and hypertext as a replacement for paper computer user manuals [35]. Shneiderman has conducted a number of experiments in hypertext usability, chiefly related to information retrieval (e.g., [36]). Other usability studies include [13] and [26]. Discussions of usability issues in general can be found in [28], [41], [37], and [38].

3. Problem Reduction Theory

The development of a theory of problem reduction may be classified into three schools of thought: decision analysis, decision making, and applications modeling. Contributions from the decision analysts have centered on the issue of managing and solving complex problems. Raiffa, in his classic work, suggested that a larger, more complex problem could be decomposed if a decision maker can judgmentally make a resulting group of sub-problems independent [34]. Application of decomposition to large scale problems can create a complex network of interacting elements and the assumption is that the union of smaller problems will equal the larger problem. Heuristics also play a role in solving for complex problems. Various heuristics could be applied to help construct a classification of subproblems. The use of heuristics involves constructing a sequence of mapping between classifications corresponding to each type of generic operation, or subproblem, in the solution of a complex problem [9]. The decision analysis approach thus leads to the concept of reducing problems to some subset that appears to be independent, and then merging the sub-problem solutions to solve for the more complex problem. The concept of mapping and classification has direct implications for hypermedia supporting organizational applications of decision analysis.

Decision making theorists principally have dealt with the cognitive processes involved in solving problems. Newell and Simon introduced the concept that problem solving is in part focused on finding some path from the initial problem state and space to some desired states [29]. The process of problem solving with decomposition is to have information that permits factoring one large problem into several smaller problems and retaining "...a record of the successful path [28, page 98]." A number of methods have been suggested for reducing or decomposing problems, but all proposed methods of redefining problems to a more manageable set of sub-problems focus on reducing complexity to a hierarchy of simpler subsystems [40]. One proposed method is to create a map of nodes and links involving a hierarchical order of concepts to help solve large, "messy" problems [10]. One foundation for a map, or network, of sub-problems is the way individuals process the information and subsequently refer to the information. Decision makers need to process a great deal of information, organize it, and have memory references to it. Problems may be restructured vertically with reduction, or laterally by linking sub-goals so that several levels of problems and solutions may exist when analyzing a complex problem [16]. The concept of chunking is essential to the theory of decision making; the chunk represents the results of decomposition and provides memory as long as search rules are defined to retrieve the chunk [15]. In summary, the contributions of the decision making school to the potential development of hypermedia support includes the concepts of hierarchical structures, linking, and handling of information with chunks.

Modeling efforts to support decision making utilize problem reduction for solving applied problems. A problem reduction system can be developed to reduce problems into sub-problems and the sub-problems can be reduced to the lowest level forming a basis for recognizing similar problems when encountered [6]. In modeling, complexity triggers the need for reduction as well as integration. For problem structuring facilitation in modeling, Pracht suggests that visual images may be helpful to represent mental models of a complex system [33]. Being able to graphically visualize a model's hierarchy, links, and information may be valuable support in problem modeling and structuring [33]. The implications to hypermedia support of decision making are quite clear: modeling necessitates problem reduction into chunks that can be visually represented and navigated to help decision makers.

Review of recent work involving problem solving suggests that a great deal of opportunity exists to employ the theory of problem reduction in using hypermedia to support organizational decision making. In a recent study, protocol analysis was utilized to examine the effects of non-hypermedia decision aids on problem solving, but the researchers did not address the issue of problem structuring [23]. In a comprehensive review of managerial problem solving, Smith acknowledged the difficulty of characterizing the problem being solved and urged theorists to focus efforts on categorization that would lead to support of decision making [37]. Such a categorization of problems may involve problem decomposition and the pattern of decomposition. Work with the Business Management Lab involving simulation points to the need, when dealing with complex problems, for having the ability to specify linkages of variables for new relationships and the value of having some cognitive map that helps in dealing with variables, their values, and their relationships [5]. Hence, there is a need for a structure to help manage complexity, a map to facilitate access to information, and the opportunity for learning. Complex problem solving involves a host of variables; however, structural knowledge of relationships has been found to be very important in supporting decision making [12]. Diagnostic problem solving is enhanced with the decomposition of global criteria into local optimization criteria that are then connected by links which will propagate appropriate updates for any changes that might occur [30]. Lawrence notes that complexity is composed of a number of dimensions, yet there must exist some form of linkage or feedback to deal with a complex situation that can be broken down into a series of decisions [21]. One research effort produced a problem reduction model that provided for managing dependencies between sub-problems [24].

This brief review supports the notion that problem reduction theory is important in explaining how decision makers approach problems. Common elements amongst the various schools of thought on problem reduction include a representation of hierarchical levels, the process of linking information, grouping information into logical chunks, and assimilating information for a solution. Current research has not taken advantage of theoretical implications of problem reduction, especially given the capabilities of hypermedia to fulfill the role of technical support in chunking information, typing and otherwise organizing information into various classifications, and linking information together in various configurations including problem decomposition hierarchies.

4. Theoretical Framework and Proposition

The theory of problem reduction would account for decomposing large, complex problems into more manageable sub-problems, solving the sub-problems, and then assimilating or integrating sub-problem solutions to arrive at a decision. Hypermedia may be an excellent enabling technology for decision makers that offers the facility of not only tracking immense amounts of information, but also providing a mechanism for classifying and organizing information in an hierarchical fashion that emulates the decomposition. Decision makers utilizing hypermedia in problem reduction would be expected to perceive valuable facilitation in support of cognitive processes of decision making for complex, less structured problems.

Technology can facilitate this process by freeing the decision maker to concentrate on evaluation rather than becoming overwhelmed by detail and complexity. In essence, hypermedia should significantly improve the decision process for complex problem solving by allowing the decision maker to concentrate on limited numbers of issues at any one time, yet having the entire range of decision support available. Moreover, hypermedia would truly facilitate the jumping from one level or one thought to another that characterizes cognitive strategies, especially when using decision support systems, expert systems, and executive information systems.

Study of decision making for the class of problems that would be candidates for hypermedia support of problem reduction could involve three main categories of variables (cognitive, perceptual, performance) as shown in Table 2. Cognitive variables have been extremely difficult to

Cognitive	Perceptual	Performance
Thought Flow	Confidence	Time to Solution
Decomposition	Facilitation	Optimization
Chunk Referencing	Ease of Use	Accuracy/Errors
Memory/Retention	Flexibility	Data Assimilation
Learning/Relearning	Meet Needs	Tool Usage
Spontaneous Linking	Adaptive to Style	Frequency of Use
Assimilation Patterns	Risk	Number of Alternatives Tested

Table 2: Potential Variables for a Research Program on Hypermedia Support of Problem Reduction

obtain; most research has depended upon self reporting either during the decision making process with protocol analysis or ex post facto with narrative recall. Hypermedia affords the opportunity to objectively and unobtrusively capture certain cognitive variables. Table 2 shows some potential cognitive variables that might be useful in a research program to better understand decision making and evaluate emerging and enabling technologies that claim to support decision making. Thought flow can be a map of what a decision maker may demonstrate in navigating through a problem. Different manipulations of independent variables (e.g., task complexity, size of problem) in design of experiments could lead to comparisons based on thought flow. Similarly, the patterns of decomposition of problems, chunk referencing for information, memory/retention model features, ability to learn or support for relearning, spontaneous linking to follow idea generation, and assimilation patterns of how integration takes place may all be of value in providing easily replicatable evidence of the impact of empirical manipulations involving cognitive processes.

Other variables shown in Table 2 have routinely been employed in research concerning decision support (see for example, [4]). The perceptual variables are relatively easy to assess by asking decision makers to position their responses on some relative measurement scale. Variables which may be of interest to the researcher include confidence in the hypermedia model, how the model facilitated decision making, the ease of use of the model and model features, flexibility of the model, whether the model meets the needs of the decision maker for depth of analysis, if the model was adaptive to one's decision making style, and how much perceived risk may be involved using the model. Similarly, performance measures have routinely been employed in research and have characteristically been easy to obtain. Time to solution, variance from optimal solutions, errors, amount and types of data utilized, which tools were utilized and under what circumstances, frequency of use of features, and sensitivity testing may be important variables and may conveniently be captured in hypermedia systems.

Process tracing in hypermedia offers great promise to researchers involved in organizational decision making because of the ability to address the problem of evaluating task manipulations on cognitive processes. In the past, research has focused on perceptual and performance variables. Process tracing adds a new arena for researchers. This research project is a first attempt to demonstrate the value of hypermedia in measuring cognitive variables. This exploratory, pilot study was undertaken to ascertain if process tracing can show a decision maker's cognitive thought flow for solving an organizational decision amenable to problem reduction. Therefore, the major research focus of this study is to empirically demonstrate the following:

Proposition: Hypermedia process tracing can show a decision maker's cognitive thought flow in the process of arriving at a solution for a problem that can be decomposed.

Although this study is an exploratory effort, there are a number of hypotheses that could be employed in future studies. Given the above discussion, and as an illustration only, we offer two examples each for cognitive, perceptual, and performance issues of some potentially interesting hypermedia research questions grounded to the theory of problem reduction.

Question 1: Do decision makers with structured hypermedia models show different thought flow in problem solving than those with less structured hypermedia models?

Question 2: Do decision makers with structured hypermedia models have fewer references to chunks than those with less structured hypermedia models?

Question 3: Will hypermedia increase perceived facilitation of decision making compared to traditional decision support technology?

Question 4: Will hypermedia influence perceived confidence in decision making compared to traditional decision support technology?

Question 5: Can hypermedia improve the time to reach a decision compared to traditional decision support technology?

Question 6: Can hypermedia increase the support for testing a number of alternatives, compared to traditional decision support technology?

5. Pilot Study

A pilot study was undertaken to demonstrate the feasibility of the proposition that hypermedia process tracing can show a decision maker's cognitive thought flow in the process of arriving at a solution for a problem that can be decomposed. This consisted of two main phases: (1) construction of an operational prototype hypermedia system meeting the desired functional criteria; and (2) performing an empirical pilot test of the system in operation with subjects. These two phases will be described in turn below.

5.1 Construction of an operational prototype

The functional criteria identified for the operational prototype flow from the previous sections:

1. It must support a realistic problem solving task which might be typical in the environment of modern organizations.

2. It must support problem decomposition into sub-problems, solving of the sub-problems, and assimilation of sub-problem solutions into an overall solution.

3. It must support links and navigation methods between chunks and other components (at minimum, pre-defined bi-directional object-level links; ideally also dynamically defined and meta-level links), with visual mapping features and a direct-manipulation user interface.

4. It must have integral, unobtrusive process tracing features which will produce a log of events interpretable as the manifestations of cognitive processes, and facilitate the testing of hypotheses related to variables in Table 2.

As described in more detail later, the task chosen for the pilot study is that of performing financial analysis within the structure of a DuPont chart. A DuPont chart is a hierarchical chart designed to show the relationships between certain ratios and financial variables in a firm. It is a useful financial analysis tool in organizations, and is discussed in many introductory finance texts [8]. We feel that as hypermedia becomes more prevalent in organizational information systems, this kind of hierarchical, visually oriented financial modeling tool will become a viable alternative to current technologies such as spreadsheet systems. The overall structure of the chart is shown in the top right panel of the screen image shown in Appendix 1. The prototype we constructed is a hypermedia system which incorporates a DuPont chart and an associated financial analysis case problem.

The implementation of the DuPont chart in our pilot study prototype perhaps is best described by examining representative screen images from the prototype, shown in Appendix 1. These screen images show that three nodes of the hypermedia network may be displayed simultaneously: (1) a "home" navigational node consists of the top right panel's "variable map" and bottom left panel's "information source map" nodes, showing all variables included in this particular DuPont chart and links to various financial statements and other nodes, respectively; (2) a "variable detail" node in the bottom right panel, relating to the analysis of a particular variable and the variables used to calculate it; and (3) a textual "help" node in the top left panel which may be accessed for information about particular variables--their role in the overall chart, how they are calculated, and their interpretation and significance in the financial analysis.

The DuPont chart, as implemented in our pilot study prototype, supports problem decomposition by allowing users to "drill down" from the overall variable map to manipulate individual variables. In a variable detail node, users work with one parent/children relationship from the variable hierarchy at a time--supplying the values of child variables and the mathematical operators which relate them to allow calculation of the parent variable's value. For example, the nodes displayed in Appendix 1 show that Net Income of 114 is computed by subtracting 2,886 in Total Costs from 3,000 in Sales (all figures were in thousands of dollars for this task). While variable values may be typed in and/or directly edited, they are typically brought in through a global memory device capable of retaining variable values (in the current version, a clipboard-like mechanism capable of holding one value at a time). This not only reduces memory demands on the user but allows tracing of the source and destination of numerical values during use. To employ this feature the user visits a financial statement node such as the income statement, places a desired value in memory, goes to the destination node (a return-to-last-node navigation aid is available if appropriate), and pastes the memory contents into the desired variable. The variable detail nodes implement what has been called hypertext "valuation nodes" and "valuation links" [3] in that the nodes contain evaluatable mathematical expressions and the links allow the transmission of expression contents between nodes. As variables and mathematical operators are supplied or modified, appropriate recalculations are recursively propagated throughout the variable hierarchy to maintain valid values at all times. Through the methods just described, we support problem decomposition into sub-problems, solving of the sub-problems, and assimilation of sub-problem solutions into an overall solution.

The pilot study prototype supports links and navigation methods between chunks and other components through the use of user-selectable link icons or buttons; these are particularly prevalent in the variable map and information source map nodes. Visual mapping features are apparent from the screen images in Appendix 1, which shows two different variable map schemes used in the prototype. One scheme, shown in the top screen image, visually reinforces the hierarchical structure of the DuPont chart and explicitly indicates the existence of relationships between variables. The other scheme, shown in the bottom screen image, indicates only a gross ordering of variable sets according to the sequence used to calculate or recalculate the variable hierarchy. The direct-manipulation user interface also incorporates visual cues which are helpful to users. For example, variables for which values are supplied directly are color-coded differently from those which are calculated based on other variables (for black and white reproduction in Appendix 1, these two colors have been changed to white and gray-shared backgrounds, respectively).

The pilot study prototype has integral and unobtrusive process tracing features which will produce a log of events interpretable as the manifestations of cognitive processes. The assumptions necessary to make this a valid technique are delineated in [25]: (1) users' decision processes must at least partially manifest themselves as machine-readable events at the user interface level; (2) these events must be captured, identified, and stored in real-time; and (3) appropriate analysis of the user interface event log data must allow at least partial reconstruction of decision states, activities, and processes associated with the user's decision making. In the pilot study prototype, a number of user interface events were noted and recorded and logged to a file as a user worked. These included link traversals between nodes (to the variable detail, help, and information source nodes); and the supplying or editing of values and operators for the DuPont chart variable hierarchy. Even with this relatively modest number of defined events, users solving the DuPont chart for the value of Return on Equity (the top-most variable) produced an average of approximately eight events per minute. Analysis of the events does indeed lend itself to a variety of inferences concerning the users' cognitive processes. For example, traversal from a variable detail node to an information source node and back without then supplying a variable value, followed by traversal to a different information source node and back and then supplying a variable value, can reasonably be interpreted as an initial uncertainty as to which financial statement is the appropriate one to consult for the required information. These and other inferences can facilitate the testing of hypotheses related to several of the variables in Table 2.

The prototype is implemented in ToolBook version 1.53 [1] running under Microsoft Windows 3.1. All functions and features described here are operational and were so during the pilot test described in the next section. Continuing enhancement of the prototype is ongoing, with the primary long-range goal being the creation and maintenance of a computerized process tracing laboratory instrument which may be used in a number of hypermedia, decision making, and decision support system empirical studies. It should be noted that there is no attempt to provide a universal set of hypermedia functions provided in other hypermedia systems or proposed by other hypermedia researchers--only those elements which are germane to the goals of this study are implemented. Future enhancements may include additional features such as annotations, bookmarks, additional navigational aids, etc. as research goals require.

5.2 Performing an empirical pilot test

An empirical, controlled, laboratory study was employed to determine the feasibility of using hypermedia process tracing to represent a decision maker's thought flow while engaged in problem solving. Selection of a task for purposes of this exploratory study required that certain criteria be met. The task had to be semistructured--capable of being solved, complex enough to require judgment, without an obvious correct or optimal solution. The task also had to be amenable to problem reduction into a set of problems that exhibited more structure--easier to solve, less complex, with obvious solutions. Furthermore, the task had to be in a subject area with which organizational decision makers would have adequate experience and knowledge. Financial analysis was chosen because there exists a number of different types of financial decisions that regularly confront organizational decision makers. The specific task that was incorporated into the decision model for this study was an acquisition decision based on financial ratio analysis taken from Brigham [8]. The task involved making a decision as to whether or not to recommend acquisition of a firm, based on the analysis of financial information (net income statement, balance sheet, and ratios), and could easily be decomposed to its supporting levels of structured problems. The analysis procedures and the type of information presented for the task would be familiar to those with experience in financial analysis.

Procedures for the exploratory study had to guarantee control, enable unobtrusive data collection, provide for the elimination of learning effects, prevent participants viewing each others' work, ensure anonymity and confidentiality, and take place in a controlled environment without interruptions. For the experiment, participants were requested to meet in a computer laboratory classroom on a university campus at a specified time. Each participant was escorted to a PC station in order of arrival, with even numbered station using one version of the model and the odd stations using another version. The station number was used to identify the participants. Fifteen minutes of training was provided by the researchers in the use of the mouse to manipulate the various navigational and operational features, menu, copying, and scrolling features required by the model. A brief review (5 minutes) of the model screen layout was provided. Participants then were asked to complete a set of demographic questions and solve a "warm-up" problem. Participants then opened the model, completed analysis, responded to questions and requests for additional analysis, and waited for further instructions. Upon completion, the researchers provided a pad of paper and pen and asked each participant to write down their observations on the use of the model, the clarity of instructions, and suggestions. After everyone appeared to be finished, the researchers engaged the group of participants in a debriefing discussion for about twenty minutes for the purposes of gaining insight as to how to improve the experiment and the model.

Participants were all volunteers who were contacted by the researchers and requested to take part in an exploratory study. Ten individuals attended the study and all had financial analysis experience and experience using a mouse-based computer system. Experienced financial analysts and computer users were required since there is some evidence that there is considerable difference between how experts and novices solve problems [12] [14]. The titles of the participants included: Senior Manager of Business, Senior Financial Analyst, Manager of Strategic Planning, Coordinator of Cash Management, Manager of Finance, Accountant, and Professor. Three different organizations and two university finance faculty were represented. The demographics of the participants were characterized by an average age of 37.4 years, 7.4 years experience with financial analysis, 9.8 years experience with computers, with 3 females and 7 males who all had college degrees, three having completed at least a masters degree (including the 2 faculty with Ph.D. degrees).

Data was collected during the study in two ways. First, participants responded to questions that appeared on their monitors as they progressed through the experiment. The questions at the beginning were demographic in nature and those at the end of the session were about the solution and perceptions of using the model. Second, process tracing collected information on each participant's hypermedia navigation and usage. All data were written to a log file, which was later removed for analysis.

The process tracing recorded each event as a list of four items: (1) the name of the node where the event was initiated; (2) the name of the object (button, data field, etc.) which was affected; (3) the message type (left mouse button click, entry of a value in a data field, etc.) received by that object; and (4) the time, measured in seconds from midnight (these units were chosen to facilitate calculations involving elapsed time between events). The problem solving phase where subjects completed the DuPont chart required an average of 21.7 minutes and produced an average of 169.3 recorded events. From the event log it is possible to identify the entire sequence of changes to all variable values and operators selected.

We are investigating and developing a number of methods to aid in interpreting the event logs as manifestations of cognitive processes. One method is to create an n by n (n being the number of nodes) node traversal matrix showing all pairwise traversals between nodes. This may be extended in the manner of sequential lag analysis [2] to indicate node traversals with one or more intervening node visitations. An order 0 (direct traversal with no intervening node visitations) cognitive map drawn based on the node visitations of one of our pilot test subjects in shown at the top of Appendix 2. Another method is to produce a graphical cognitive map showing the pattern of node accesses over the course of time during a problem solving session. For the same subject, an example of this version of cognitive map is shown at the bottom of Appendix 2. Finally, we have implemented a working prototype log playback program which rapidly highlights node visitations on an overall map in an animated fashion, playing back sequences at many times their original speed. This latter method, while perhaps not suited to formal analysis or hypotheses testing methods and certainly not easily represented on paper, provides a dramatic and dynamic visual interpretation for node access patterns in a spirit similar to "flying through hypertext" [21].

6. Discussion

This research demonstrated the value of hypermedia in organizational decision making in four ways. First, integration of process tracing features into the larger system supporting problem solving was straightforward and provided an excellent means to unobtrusively capture thought flow. A cognitive map representing a decision maker's node visitation pattern is of particular interest. The map may reflect when a decision maker needs to access data versus explanations versus model calculations. During the process of problem solving, this study showed the potential of hypermedia to afford researchers the opportunity to assess stages of decision making such as how much effort decision makers spend in understanding the problem, perusing information, trial and error data manipulations, and assimilating solutions. Second, hypermedia may explicitly facilitate problem reduction through its information chunking ability. The financial model developed for this investigation required use of different sub-problem solutions with attendant sub-problem information. Hypermedia was useful in showing the structure of the problem and the relationship between the subproblem decompositions. The chunking necessary for supporting reduction was easily incorporated in the model. Hypermedia is very suitable for organizing, arranging, and displaying information required for decomposition of a semistructured problem as was demonstrated in this study. Third, hypermedia features may provide direct support of modeling in addition to mere information retrieval. The calculations required for solution to the financial analysis were clearly supported by hypermedia. Operator buttons for calculations, memory storage for variable values, and other mathematical support features necessary for problem solving were provided as computation-oriented extensions to basic hypermedia, providing the access mechanisms and tools so that decision makers could employ any of the modeling features in the process of decision making. Fourth, carefully controlled laboratory studies involving hypermedia may provide a basis for examining the consequences of manipulations of tasks, modeling approaches, and individual differences. Although this study did not manipulate the task, the empirical procedures demonstrated the capability for task manipulation. As an example, if researchers were interested in studying the impact of different hypermedia representations on a decision maker's performance for varying degrees of risk, the decision task could be manipulated for risk level. Two different views of the model were constructed for this study to demonstrate that comparisons could be made on the information presentation views. Extensive research has been conducted on the value of information presentation formats (e.g., see [43]), and hypermedia systems may enable multiple views based on decision maker preference. In summary, individual differences in style of decision making, performance, risk perceptions, and so on, may be studied with hypermedia. This study showed that perceptual variables and performance variables could both be captured with hypermedia.

Future empirical studies would benefit by enhancements identified as a result of the limitations of this pilot study. Most obviously, a larger sample size should be utilized. The size of the sample should be determined both by the specific research questions and the empirical design. Our pilot investigation was intended to demonstrate the feasibility of an empirical study of hypermedia decision support; therefore, a convenient number of participants was used rather than a required number based on statistical sample size determination. Also, research hypotheses should be used to test specific questions that are of theoretical interest. For example, do decision makers differ with respect to cognitive, perceptual, and performance variables (as shown in Table 2) when allowed to freely traverse the nesting of a problem versus when they are constrained to more structured patterns of traversal? Future enhancements could include behavioral variables such as individual differences and cognitive style of decision making. A great deal of work needs to be done to develop better reporting schemas and analysis methods for cognitive maps produced by process tracing. Future work on how to meaningfully compare cognitive maps needs to take place. Moreover, the issues of model reliability and validity need to be addressed.

The gateway to further research on hypermedia support of organizational decision making has been opened by this project. Beyond the scope of this feasibility effort exists opportunities to make a significant contribution to our understanding of organizational decision making. The enabling technologies are now available and we are just beginning to capitalize on hypermedia capabilities. Yet, we do not fully know the ramifications of emerging technologies on problem solving. Questions remain unanswered about the use and value of hypermedia sound and video in organizational decision making. The assessment of effectiveness of hypermedia in support of solving complex problems has yet to be addressed. Future research evaluating more generalized hypermedia, where decision makers build their own models to support not only problem decomposition but other paradigms, needs to be undertaken. Questions about the transferability from the lab to field need to be resolved, including whether we can successfully employ hypermedia in ongoing organizational decision making where environmental influences such as political and organizational climate factors exist. Future research may also focus on differences of hypermedia usage in decision making between individuals versus groups.

As we integrate hypermedia into organizations, it may replace, coexist with, subsume, or be subsumed by traditional computerized applications. We encourage hypermedia researchers to not only propose and develop hypermedia technology, but also to include integral process tracing features and perform systematic empirical evaluations of implemented systems. This will provide us a basis from which to measure the value of the technology, assess its impact on organizations, and better meet the needs of those organizations.

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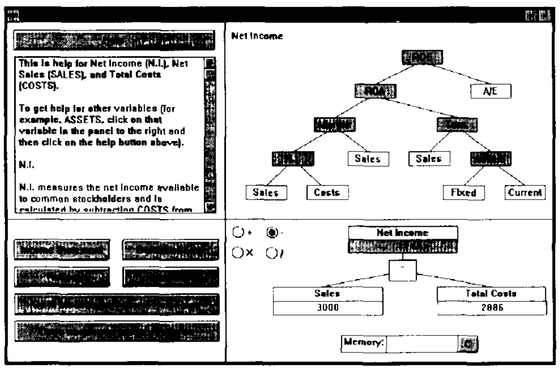
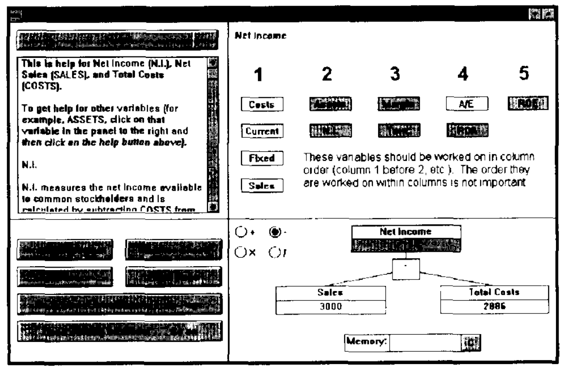
Appendix 1: Pilot Study Visual Representations

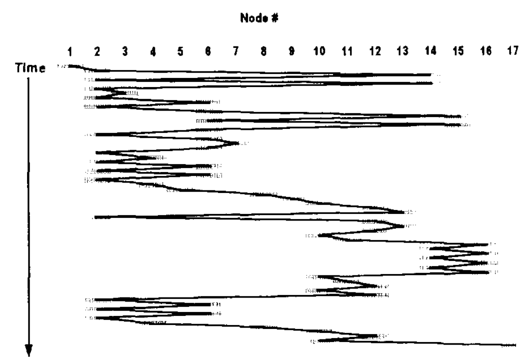




Appendix 2: Pilot Study Cognitive Maps*

To node #

From node #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1		1															
2			1	2		7						1		2			
3		1															
4		1			1			1									
5								1									
6		7					1								2		
7						1											
8									1	1							
9										1							
10											2	3					1
11												1				1	
12		1								3			2				
13		1										1					
14		2														3	
15						2											
16										1				3			
17																	



* These cognitive map fragments show the node visitations for the main problem-solving exercise in the pilot study, for one subject. They incorporate only part of the information inferable from the process tracing logs.