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VISUALIZATIONS OF PROJECT INTERDEPENDENCIES FOR PORTFOLIO DECISION MAKING: EVALUATION THROUGH DECISION EXPERIMENTS.

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ABSTRACT

Decision making is central to an organization's management of its investments across a portfolio of projects. Cognitive fit theory proposes that decision quality will be enhanced when there is alignment between the information emphasized in visual data representations and the important aspects of the decision problem. This study explores the effect of different methods of representing project interdependency data on the resulting decision quality in a simulated project portfolio management decision scenario. The findings, based on a sample of 264 experiments, show that the type of data representation used may influence the quality of the resulting decision and that the use of network mapping displays is correlated with the best results.

Keywords: Project portfolio management; data representations; visualization; network mapping; cognitive fit

INTRODUCTION

Decision making is central to an organization's management of its investments across a portfolio of projects through project portfolio management (PPM). PPM is an organizational capability of growing importance in an increasingly complex project landscape (Levine, 2005; Cicmil *et al.*, 2006; Jonas, 2010). By managing projects from a portfolio level and evaluating all projects and their interrelationships, PPM aims to improve the performance of the project portfolio as a whole. Portfolio decisions are responsible for ensuring resource adequacy, dynamic agility, and strategic alignment using a portfolio-level rather than a project-level perspective (Floricel and Ibanescu, 2008; Petit, 2011). However, PPM decisions are subject to limitations in human cognitive capability to analyze a variety of information in limited time. PPM processes are designed to assist such decision making by providing a holistic view of the project portfolio, ensuring that data are available and offering representation methods and tools to facilitate analysis of project data (Cooper *et al.*, 2001; De Reyck *et al.*, 2005; Kester *et al.*, 2011). Organizational success depends on appropriate PPM methods and tools that improve the quality of these portfolio-level decisions.

The interdependencies between projects add to the complexity of PPM decision making and must be considered along with financial, strategic, risk, resource and other factors. Portfolios of complex and interdependent projects are increasingly common and there is an identified need for better tools to understand and manage the relationships between projects. New processes, tools, and techniques are regularly proposed and evaluated in PPM literature and research (Archer and Ghasemzadeh, 1999; Dickinson *et al.*, 2001; Dawidson, 2006; Kester *et al.*, 2009). However, measuring the effect of a new tool or method is difficult because each organizational environment is different and there are many uncontrollable factors that influence project performance. While research in organizational settings can provide valuable insights, such settings do not provide a reliable and static environment where it is possible generalize findings. Simulated decision challenges in a controlled setting can complement organization based research by testing the effects of changes in a systematic method in an experimental fashion.

This paper draws upon theories of bounded rationality and cognitive fit to explore alternative data representation methods for the management of project interdependencies. The research employs controlled experimentation in a classroom setting to test the ability of three different data representation formats to enhance understanding of project interdependencies to support PPM decision making.

LITERATURE REVIEW

PPM decision making and project interdependencies

PPM is a set of organizational activities that provides a holistic framework for the management of the project portfolio. The literature highlights that PPM is primarily a strategic decision-making process which involves identifying, minimizing and diversifying risk, identifying and responding to changes, and understanding, accepting and making trade-offs (Kester *et al*., 2011; Levine 2005). PPM decisions require consideration of multiple factors and the ability to envision alternative future consequences of project decisions across a portfolio. Decision making quality has a major influence on project portfolio success (Matheson and Menke, 1994).

Best practice studies indicate that high-performing organizations use carefully compiled executive-level teams, often called portfolio review boards (PRB), to make portfolio decisions (Cooper *et al.*, 2001; Dickinson *et al.*, 2001; Killen *et al.*, 2008). The decision making requires a central view of all projects in the portfolio and the PRB is informed by methods that facilitate group decision making including portfolio maps and other graphical and visual displays (De Maio *et al*., 1994; Cooper *et al*., 2001; Mikkola, 2001); however, the maps must be customized for effective portfolio decision making (Phaal *et al*., 2006). The use of such visual data representations is correlated with better portfolio performance (Cooper *et al.*, 2001: Killen *et al.*, 2008).

PPM decisions consider the portfolio as a whole, but often treat each project as an isolated entity. The presence of interdependencies between projects can cause unpredictable interactions and reactions in the system (Aritua *et al.*, 2009; Perminova *et al.*, 2008; Collyer and Warren, 2009), and it is widely accepted that organizations must be able to understand the dependencies between projects in their portfolio in order to make appropriate project decisions for the best portfolio outcomes (Verma and Sinha, 2002; Blau *et al.*, 2004).

The management of interdependences is acknowledged as an area of weakness for PPM (Elonen and Artto, 2003). Some organizations record interdependency information along with other attributes in a project database, however the ability to use this data for decision making is limited. Interdependencies are sometimes displayed on a dependency matrix grid to inform management and support decision making, however these displays do not readily identify multi-step dependencies (Dickinson *et al.*, 2001; Danilovic and Browning, 2007). To meet the challenges of PPM, especially as complexity and uncertainty increase, researchers are active in developing and evaluating new decision-making tools (Aritua *et al.*, 2009).

Bounded rationality and PPM decision making

The bulk of PPM literature assumes that decisions are made on a rational basis within a structured PPM process. However, some authors question this assumption and find that other influences on PPM decisions can result in less than rational outcomes (Eskerod *et al.*, 2004; Christiansen and Varnes, 2008). Humans also have a tendency for bias towards excessive optimism; however, a PPM process can address such human shortcomings by improving transparency in the decision-making process (Lovallo and Sibony, 2006). In addition, humans are subject to 'bounded rationality' (Simon, 1955), which limits their ability to interpret the large amounts of data required in PPM decision making, and results in decisions that are not always rational. Decisions are often required to be made without complete and accurate information. This and the human cognitive limitations in interpreting the information, and the finite amount of time available to make decisions, contribute to the 'bounded rationality' that affects PPM decision making, especially in complex and dynamic environments.

Most PPM decisions involve human judgment, often in an executive review meeting or PRB where each individual's experience, diversity, and judgment contributes to a powerful team perspective for decision making. However, complex decisions are strongly affected by human cognitive constraints (Foreman and Selly, 2002). Humans are limited in their ability to recognize interdependencies and resultant flow-on effects from their decisions and actions in complex systems. While human capabilities are limited, research suggests that visualization techniques can compensate for limitations in working memories (Tergan and Keller, 2005).

Managers are asked to make decisions based on increasing volumes of information (Shim *et al.*, 2002), and the time available to digest and analyze the information is often limited (Agor, 1986; Dane and Pratt, 2007). Decisions made with inadequate time are likely to be made with limited evaluation of alternatives and exhibit lower decision quality (Ahituv *et al.*, 1998; Janis and Mann, 1977; Svenson and Maule, 1993). For example, time pressure is a factor contributing to budget over-runs in project management environments (Williams, 2005; Cicmil *et al.*, 2006). In this environment of incomplete information, limited cognitive capabilities, and limited time, PPM decisions are often affected by bounded rationality and therefore may not be optimal (Blichfeldt and Eskerod, 2008). PPM processes and tools aim to alleviate one or more of these challenges to improve decisions – for example by filtering and formatting information in a way that aids interpretation in the time available and within human cognitive limits. Many forms of computer-based decision support systems have been suggested, with the aim of streamlining decision making and thus making better use of decision-making time (Shim *et al.*, 2002). However, while many highly computerized solutions have been offered, there is little evidence of the use of such methods in PPM practice.

Cognitive fit and data representation tools

The cognitive fit theory explains how the fit between the method used to represent data and the nature of the decision task affects the quality of the resulting decision (Vessey, 1991). Different types of data representations emphasize different aspects of the data (for example tables usually provide symbolic representation while graphics may display spatial relationships) while the needs of decision-making tasks vary in the information required from the data. The decision maker must create a mental model to analyze the data with respect to the task to arrive at a solution. When the data representation and the decision making task are aligned, this cognitive fit is proposed to enhance decision-making ability by enabling the decision maker to directly apply the interpretation of the data representation to the problem-solving task. However, when the two are not aligned, the decision maker must perform further conversions of the data in order to address the problem, resulting in lower decision accuracy and higher time requirements.

A number of experimental studies provide support for cognitive fit theory. For example, a study of forecasting in an accounting setting demonstrated that alignment between the data and task dimensionality (3D visualizations of multi-dimensional data) improved the quality of the forecast (Dull and Tegarden, 1999). In another study, graphical representations of geographical adjacency and proximity in maps were found to provide increasing benefits as task complexity increased (Smelcer and Carmel, 1997). Cognitive fit is used to explain the relationship between buyer behavior and different web formats that display the same information (Hong, Thong, and Tam, 2004) and an experimental study of knowledge and expertise visualization methods found that decision speed was enhanced when compared to tabular information, but not decision quality (Huang *et al*., 2006). A fractional factorial experiment showed that graphs provided better fit in a study of bankruptcy predictions; the graphs provided integrative spatial information while preserving the characteristics of the underlying data. The cognitive fit model relies not only on the task and the data representation; the spatial visualization abilities and other individual differences are also at play in the relationship between the task, data representation and quality of the decision (Smelcer and Carmel, 1997; Vessey, 1991).

Visual representations and decision making

The combination of human cognitive skills and visual representations of data that have strong cognitive fit with the decision problem have the potential to greatly enhance PPM decision making. Visual data representations that harness the executive decision makers' experience and judgment will provide particular benefits in the PRB team environment. Visual representations of data are shown to assist with the analysis of complex data (Mikkola, 2001) and help communicate and shape strategic thinking (Warglien and Jacobides, 2010). These visual representations can provide an effective format for representing and communicating information to support strategic decision making by illustrating complex multi-dimensional aspects of decision problems in a simple and powerful manner (Meyer, 1991). Visual information is cognitively processed while preserving spatial orientations and interrelationships. Research has found that graphical data displays can aid in the attention, agreement, and retention of strategic information (Kernbach and Eppler, 2010).

Improvements in computers and software-based tools offer many new methods for collecting and displaying information (Dansereau and Simpson, 2009). Human skills in analysis and pattern finding combined with computer-generated graphics produce a powerful and flexible cognitive system, taking advantage of the strengths of both humans and computers (Tergan and Keller, 2005).

The power of visualizations to support decision making is only beginning to be exploited, and there is a need for more research in this area (Warglien and Jacobides, 2010). Cognitive fit is important, and visual representations of information must be customized for the task to best facilitate decision making. Some decisions require visualizations that display multiple factors, capture historical events, and reveal complex relationships (Platts and Tan, 2004). Matrix displays have particular strengths in evaluating and sharing information (Bresciani and Eppler, 2010), and can present multiple types of information in '2½-dimensional' displays that are very powerful if well designed (Warglien, 2010).

A wide range of software solutions are available to assist with PPM data management and decision making. These software solutions range from targeted utilities for the creation of specific graphical displays to comprehensive systems that aim to support all aspects of the PPM process. A visual 'dashboard' is often included in PPM solutions, and most support the development of visual data displays such as portfolio maps.

Network maps as a visual PPM tool

While portfolio maps are a form of visual data representation that shows benefits when applied in PPM (Killen *et al*, 2008; Cooper *et al*, 2001), they have limitations in that they do not show the relationships between projects. Network maps, on the other hand, visually display relationships between nodes in a network and reveal accumulated network effects (Scott, 2008) and are easily created by software-based tools. Network maps can reveal patterns more clearly than verbal or matrix displays and have been shown to provide benefits for decision making in mathematics, biology and economics (Hanneman and Riddle, 2005). A common form of network mapping, social network analysis (SNA), facilitates organizational decisions through the display of relationships between people or organizations (Cross *et al.*, 2002; Anklam *et al.*, 2005; Scott, 2008).

In complex project portfolios, interdependencies often exist in a web of interactions. Therefore network mapping displays, with their ability to visualize 'webs' of connections between nodes, may have high cognitive fit with the problem of understanding and managing project interdependencies. 'Visual project maps' (VPM) have been proposed as a method to apply network mapping approaches to project portfolios to improve the understanding of project interdependencies (Killen *et al.*, 2009; Killen and Kjaer, 2012). VPM displays each project as a node in the network and uses arrows to identify relationships or interdependencies between nodes. The creation of VPM displays are aided by network mapping software such as NetDraw (Borgatti, 2002) or NodeXL (Hansen *et al.*, 2011). Figure 1 shows an example of a VPM type of display.

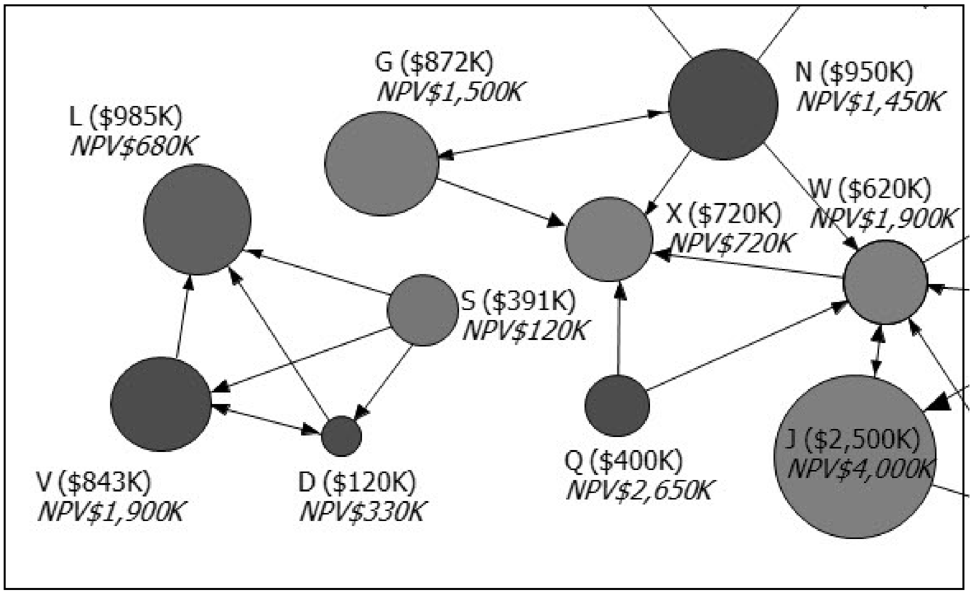

Figure 1: Portion of a visual project map (VPM). Labels provide project name, investment required and NPV. Circle size reflects investment required.

As it is a new tool for the management of interdependencies, VPM has been first tested in a few exploratory studies. VPM aided the analysis of projects, programs and portfolios in a defense setting (Durant-Law, 2012) and showed benefits as a decision making or communication tool for PPM in two organizations (Killen and Kjaer, 2012). These initial tests in organizational settings confirmed the interest and potential application of the method, however further research is needed to isolate the effects of introducing VPM. The experimental study outlined in this paper was designed to provide a better understanding of whether and how VPM can assist with the management of project interdependencies in project portfolios.

RESEARCH HYPOTHESES

The decision-making challenges presented by increasingly complex project portfolios are highlighted in the literature. There is an established need for better methods to evaluate project interdependencies to support PPM decision making. Previous findings that reveal positive correlation between the use of portfolio maps and PPM outcomes illustrate how visual data representation tools can assist with PPM decision making. A new network mapping-based data representation tool, VPM, has been introduced and applied in organizational settings; however it is unknown how VPM and options for representing interdependency data compare in their ability to affect the resulting PPM decisions.

Graphical data displays provide advantages when combined with human cognitive capabilities during decision making (Tergan and Keller, 2005), and these advantages are proposed to be stronger in displays with a higher degree of cognitive fit. Cognitive fit theory suggests that each type of data representation tool will have a different level of cognitive fit with the problem (Vessey, 1991). In this study, three different representations of interdependency data were compared for their ability to improve understanding of project interdependencies and enhance decision quality in complex project portfolios. The methods under investigation were (1) VPM –

a network mapping display, (2) Dependency matrices – a matrix display and (3) Tabular list – a list of dependencies within a column of a spreadsheet or database.

VPM displays, with an ability to directly represent the connections between interdependent projects, and to visually reveal the multi-step dependencies that are not easily seen in the other displays, are proposed to have the highest degree of cognitive fit and therefore to contribute most strongly to decision quality.

Therefore, the first hypotheses addressed in this study are:

> H1: The type of tool used to evaluate project interdependencies will be correlated with the quality of the resulting PPM decisions in complex project portfolios.
>
> > H1(a): VPM displays will contribute to better quality PPM decisions than the other tools in complex project portfolios.

Time pressure is another challenge highlighted in the literature; time pressure can have detrimental effects on decision-making ability (Janis and Mann, 1977; Svenson and Maule, 1993; Ahituv *et al.*, 1998). As time pressures are often unavoidable, it follows that tools that reduce the perception of time pressure or the negative effects of time pressure will enhance PPM decision making. Graphical data representations can allow data to be cognitively processed while preserving spatial orientations and interrelationships (Meyer, 1991) and therefore may require less data conversion to evaluate interrelationships. It is proposed that the different visual tools possess different degrees of cognitive fit with the task and will provide different levels of time saving benefits in the analysis of interdependencies. VPM displays are proposed to have the highest degree of cognitive fit and to alleviate time pressure better than the other tools. If users are more likely to feel they have enough time to make a decision with a particular tool, then that tool is more likely to provide benefits in less time, reduce the negative effects of time pressures, and lead to better decisions. The second and third hypotheses are:

> H2: The type of tool used to evaluate project interdependencies will be correlated with the perception of the adequacy of the time allocated to the decision task.
>
> > H2(a): Users of VPM displays will report higher levels of time adequacy than users of other tools.
>
> H3: Perception of time adequacy positively relates to the quality of the resulting decision.

A higher degree of cognitive fit should enhance the power of human cognitive capabilities to accurately recognize the interdependency relationships in the project portfolio. VPM displays are proposed to have the highest level of cognitive fit with the interdependency evaluation task, and should therefore result in better interdependency understanding. Therefore the fourth set of hypotheses is:

> H4: The type of tool used to evaluate project interdependencies will be correlated with the level of understanding of the interdependencies in the portfolio.

H4(a): Users of VPM displays will report higher levels of understanding of the interdependencies in the portfolio.

Improved understanding of the interdependencies in the portfolio is desirable because it should lead to better decisions. A system with better cognitive fit that enhances human cognitive capabilities to understand interdependencies is only of value if that understanding is translated into better decisions. We propose that the quality of the decision will be related to the level of understanding of project interdependencies. Therefore the fifth hypothesis is:

H5: The level of understanding of project interdependencies is positively related to the quality of the decision.

Figure 2 displays the five hypothesized relationships between the type of tool used to visualize project interdependencies and the resulting decision quality.

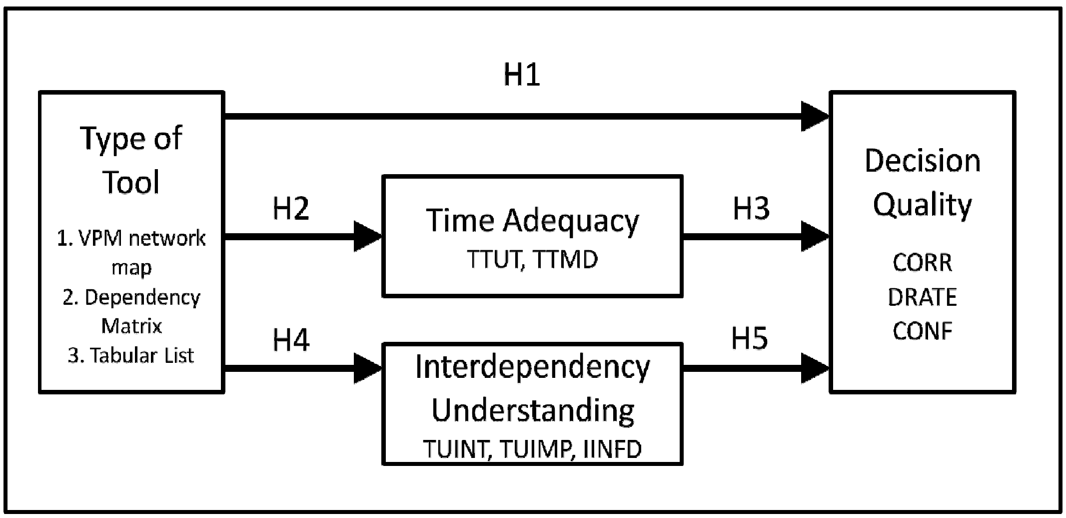

Figure 2: Conceptual model linking the type of tool, perception of adequacy of time, level of interdependency understanding and decision quality.

RESEARCH METHOD

Methodology

A simulated decision task in a controlled classroom setting was used to test the five hypotheses. Although experimental research is common in fields like psychology, economics, or marketing, it is not common in project management or PPM research and the research reported in this paper represents an exploratory application of experimental research in such settings. The few related studies reported in the literature include experimental approaches to simulate resource allocation and sharing decisions in a project environment (Bendoly and Swink, 2007) and to understand decision-making processes and learning effects in the project and portfolio management domain (Arlt, 2011).

Experimentation was selected to complement organization-based research in this study by providing a reliable and controllable environment where the effects of changes can be measured. The experimentation in the current study was designed to balance the principles of realism and simplicity as summarized by Grossklags (2007). A degree of realism was included by proposing a plausible scenario based in a business environment. Simplifying the scenario enabled the participants to focus on the central task, and the controlled setting removed many of the confounding factors that would impact research in an organizational setting.

Experimental data displays

The experiment evaluated and compared the use of different methods of presenting project interdependency data. Three different types of data displays were developed for this study; VPM (the network mapping display), a Dependency Matrix, and a Tabular List. Each of the displays contains the same information, and each has been color coded to highlight the strategic importance of the projects in the portfolio. A rainbow spectrum was employed where red and orange were used to highlight highly strategically important projects, and green and blue were used for projects that are less important strategically. In addition to strategic importance and dependency data, the scenario also included financial information (investment and projected return on investment).

The Tabular List and the Dependency Matrix displays were created based on approaches commonly used in industry to represent project interdependencies. The Tabular List presents project interdependencies in a single column as part of a spreadsheet. The Dependency Matrix display provides a deeper level of detail by highlighting dependency relationships in the cell corresponding to the pair of interdependent projects (in the row and column).

The newly proposed method, VPM, visualizes project interdependencies based on a network mapping approach. An increasing range of network mapping tools facilitate the creation of such displays, making it practical to consider the introduction of such displays to support PPM decisions. The VPM display (as per the sample in Figure 1) is proposed to have the highest level of cognitive fit with the interdependency analysis problem, as each interdependent set of projects is directly connected by an arrow, and as the multi-level interdependencies are also easy to visualize.

The experiment reported below was designed to reveal the potential influence of the type of data representation on the resulting decision. Visual displays were created based on identical project interdependency data in each of these three formats and randomly assigned to research participants as detailed below.

Research design and experimental session detail

Postgraduate students participated in this study as part of a course in technology management. Students are often used as research subjects in experimental research and can provide relevant input when they have an appropriate background (Arlt, 2011; Bendoly and Swink, 2007; Dull and Tegarden, 1999). The student participants in this study have completed an engineering or technical undergraduate degree and are already familiar with project management concepts which aided their suitability as research participants. However, it must be acknowledged that the use of students may introduce bias as there may be a lower degree of diversity among the group and common source bias may result, and they do not usually possess the same level of experience and maturity as practicing managers involved with PPM decisions. Participation in the research provided advantages to the students as the topic is relevant in industry and served to augment and extend their education. As this research involved students, the university ethics clearance was obtained and the research was designed so that participation was voluntary and confidential.

The research design was pilot tested twice, first with seven participants and then with twelve. Following feedback from the pilot testing, the presentation of project data and the visual data displays were adjusted and the procedure for the warm-up task was refined. The pilot testing was also designed to capture results in five-minute increments to help determine the optimal time limit for the experiment, a 'trial and error' approach commonly taken in such research (Svenson and Maule, 1993). The pilot testing indicated that 15 minutes was about the right amount of time – enough for most students to absorb the data and make a decision but within a tight enough timeframe to highlight the effect of time pressure.

The experiment was embedded in an 80-minute educational session on the topic of PPM and project interdependency management. At the end of the experiment students were asked to fill out a short survey that collected data on the decisions made and on the participants' perceptions of time adequacy, confidence with the decision and degree of understanding of the project interdependencies. The decision scenario was developed based on a realistic challenge – it asked students to reduce the budget by ten per cent by selecting one or more projects to cancel (remove from the portfolio). The scenario was complex due to the high number of interdependencies between projects in the portfolio.

During the class session, students were randomly assigned one of the three tools for their decision task, and were provided with a set of materials for the task using their assigned tool. A warm-up task conducted before the main decision task helped students learn about the use of their assigned tool and aimed to reduce the learning effects inherent in the experiment by allowing students to move up on the learning curve. During the main decision task, students evaluated identical data on the 26 projects in a generic project portfolio. The following information was provided for each project: investment and net present value projections, a rating for degree of strategic fit, and information on project interdependencies in one of three data display formats. For simplicity, all project interdependencies were assumed to be equal; varying types and strengths of relationships were not considered. Students were given 15 minutes to complete the decision task. In this time, they were required to review the information provided and decide which project or projects to cancel to trim the portfolio budget by ten per cent. During the decision process, students were asked to balance the following considerations with equal weighting: the interdependencies between projects and any flow-on effects from their decisions to cancel projects; the impact on strategic fit; and the return on investment. Although simplified for the purposes of this experiment, this type of scenario where multiple types of data must be balanced reflects the challenges faced by PPM decision makers.

Survey and item development

The research participants recorded their decision and provided responses for several items in a short survey immediately following the 15 minute decision experiment. The eight items that were designed to test the hypotheses are listed in Table A1 in Appendix A. The items CORR and

DRATE were rated based on each participant's decision. The remaining items employed anchored 5-point Likert scales to collect perception-based responses from the participants.

Three measures of decision quality were used to test Hypothesis 1 and determine whether the type of tool used to evaluate project interdependencies is correlated with the quality of the resulting PPM decisions. Based on the decision entered by the participant, a binary rating (CORR) was created with a value of 1 for the correct decision and 0 for any other decision, and another rating (DRATE) was rated on a scale of 1–5 based on how well the decision balances the required criteria and represents an optimal decision, with 5 representing the optimal decision and 1 the least optimal or most nonsensical decision. The rating acknowledged the gradation in decision quality, but required the use of judgment that could introduce bias. To reduce this bias, two researchers participated in a blind rating process (with no knowledge of the tool used or class session of the participant) and then discussed their decisions and agreed on the final ratings for DRATE. The third measure of decision quality is a perception-based item (CONF) that measures participants' confidence in their decision. Perception-based responses are often used in survey research and are accepted as reliable indicators of reality. These three decision-quality ratings were correlated with tool type to address H1.

Hypothesis 2 proposed that the type of tool used to evaluate project interdependencies will be correlated with the perception of the adequacy of the time allocated to the decision task, and Hypothesis 3 proposed that perception of time adequacy positively relates to the quality of the resulting decision. To test H2 and H3, two items on the research participants' perceptions of time adequacy for understanding the tool (TTUT) and to make the decision (TTMD) were correlated with decision quality measures and tool type.

Hypothesis 4 suggests that the type of tool used will be correlated with the level of understanding of the interdependencies. Three final items assessed whether the tool used was instrumental in the understanding of project interdependencies and portfolio effects of decisions (TUINT and TUIMP), and whether the interdependency information influenced the decision made (IINFD). Findings from these items are correlated tool type to address H4.

Hypothesis 5 proposes that the level of understanding of project interdependencies is positively related to the quality of the decision. The items TUINT, TUIMP and IINFD are correlated with decision quality measures to test H5.

Data collection and analysis

The experimentation was conducted in seven postgraduate technology management classes during 2011 and 2012 and resulted in 264 valid survey responses from 271 students. Responses were considered invalid if participants did not identify which tool they used during the experiment or selected more than one tool; these invalid responses were ignored during the data analysis. The valid responses represented a random allocation of tools across the seven class sections; 91 participants used a VPM display, 87 used the Dependency matrix and 86 used a Tabular representation. Although the experiment was designed to allocate the tools equally across the sample, the numbers are slightly different due to the use of seven class sections where class numbers are not always divisible by three and the removal of some invalid surveys.

Mean and standard deviations for the survey items are presented in Table A1 in Appendix A.

The student's t-test for independent samples (referred to as the t-test) was used to evaluate responses between groups of respondents based on tool type used during the experiment. Groupings were set up for users (1) and non-users (0) for each tool. Levene's test for equality of variance was used to determine the applicability to the 'equal variance assumed' or the 'equal variance not assumed' t-test values (Collis and Hussey, 2003; Garson, 2012). The level of significance of the differences in means based on these groupings is identified in figures 3, 4 and 5 using the symbol * for findings that are significant at 0.10 or better.

The student's t-test was also used to test for any significant differences in responses based on the class session. Independent sample t- tests were conducted between pairs representing all combinations of the seven classes. No significant differences were found between item responses based on the class session attended.

Bivariate Pearson correlations were used to test correlation between the 5-point scale items. Tests for normal distribution revealed acceptable kurtosis of the data; however, data for a few of the items were negatively skewed, and so nonparametric analyses were also conducted using Kendall's tau and Spearman test. These tests confirmed the significant relationships identified using Pearson's Chi squared tests with only minor differences between the Pearson results. Therefore, for simplicity the data have been reported using the Pearson format. All statistical results represent two-tailed analysis. Significance levels are reported for each correlation.

FINDINGS AND DISCUSSION

All but one of the primary hypotheses identified on the conceptual model in Figure 2 were supported by the findings. The only exception was that no significant difference was found between perceptions of time adequacy and tool use to support Hypothesis 2. The findings related to each hypothesis are detailed below.

Hypothesis 1: The three measures of decision quality were used to determine whether tool type is related to decision quality. Overall, 17 per cent of respondents arrived at the correct and optimal decision (CORR = 1) during the decision task. As shown in Figure 3, the percentage of research participants that made the optimal decision was highest for the group that used the network mapping VPM tool, with 28.6 percent of the participants achieving an optimal decision in the time allowed. Just over ten and eleven percent of the decisions made using the other tools, the dependency matrix and the Tabular list were optimal.

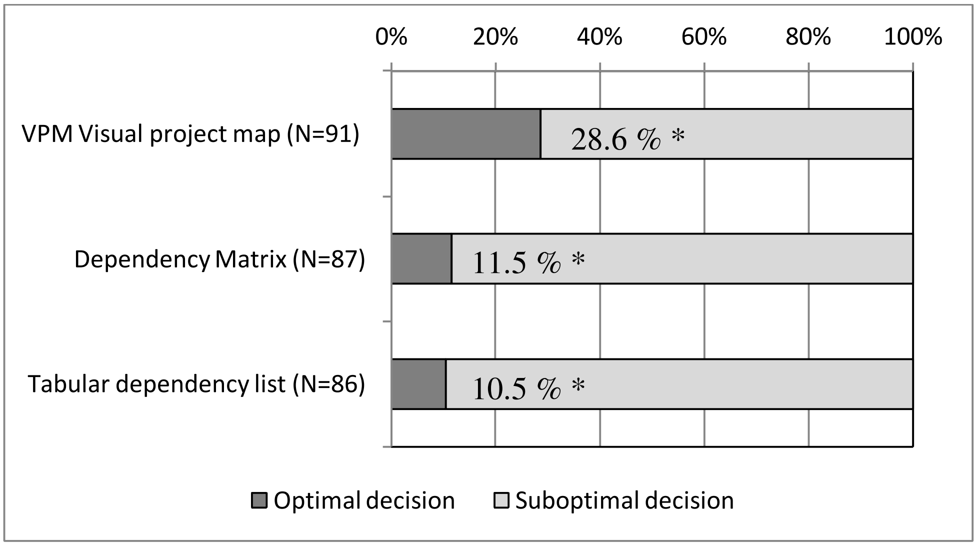

Figure 3: Percentage of optimal decisions (CORR=1) per tool type (* = indicates 0.10 or better significance of the difference between use and non-use of a tool)

An alternative view of the relationship between tool type and decision quality was developed using a rated degree of decision quality that acknowledges the continuum between 'best' and 'worst' decisions. Overall, the mean value for DRATE (rated degree of decision quality) was 2.80 with a standard deviation of 1.475. Figure 4 illustrates the mean values for DRATE for groups using each tool. Differences between each tool are significant and the use of the VPM tool resulted in the highest values for DRATE, with a mean improvement in the decision rating of 0.759 compared with users that do not use VPM (sig 0.000).

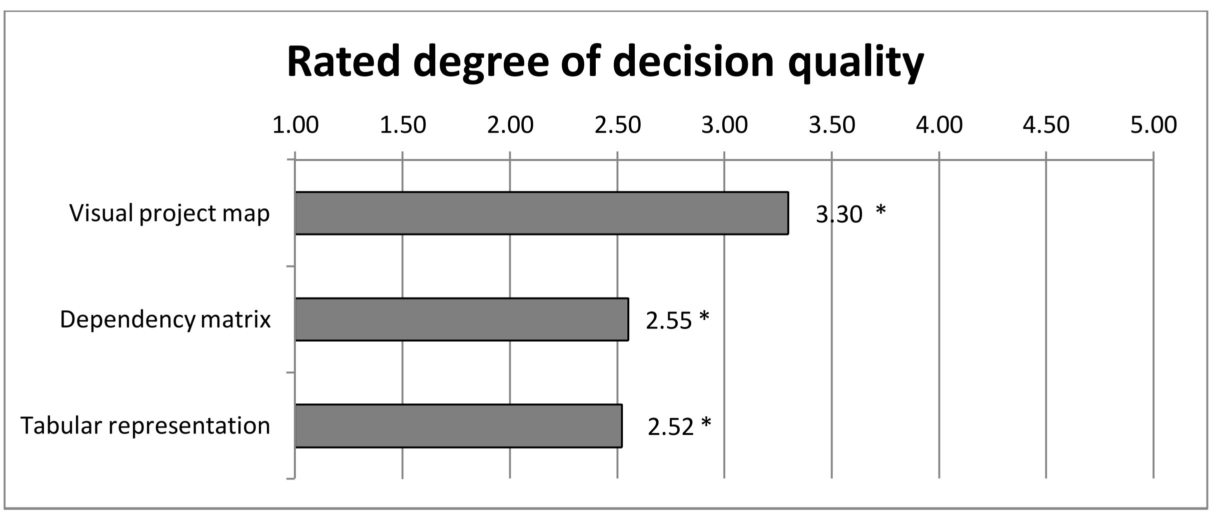

Figure 4: mean rating for decision quality per tool type (* indicates 0.10 or better significance of the difference between use and non-use of a tool).

These first two measures of the quality of the decision, CORR and DRATE are highly correlated. The mean value of DRATE for respondents where CORR=0 (not the optimal decision) is 2.39 whereas the mean value for DRATE when CORR=1 is 5.0 (mean difference of 2.61, sig 0.000).

The final measure of decision quality, CONF (participants' level of confidence in their decision) did not show any significant differences that corresponded to the use of one of the tools. However, the level of confidence correlated very significantly with the rated decision quality (DRATE) (Pearson 0.322, sig .000).

Overall, these findings support H1 and H1(a). The type of tool used to evaluate project interdependencies correlated with differing levels of decision quality as measured by CORR and DRATE, and the use of VPM displays corresponded with the best decision quality results as hypothesized.

Hypothesis 2: H2 proposed that the type of tool used to evaluate project interdependencies will be correlated with the perception of the adequacy of the time allocated to the decision task. Comparison of the perceptions of time adequacy with type of tool used did not reveal any relationships strong enough to statistically support H2 or H2(a).

Hypothesis 3: H3 proposed that perception of time adequacy will positively relate to the quality of the resulting decision. As shown in Table B1 in Appendix B, decision quality correlated strongly with perceptions that time was adequate. At the 99 per cent confidence level, respondents that felt they had enough time to understand the tool used (TTUT) and to make decisions (TTMD), made significantly better decisions, and had higher confidence in their decisions.

Hypothesis 4: H4 proposed that the type of tool used to evaluate project interdependencies will be correlated with the level of understanding of the interdependencies in the portfolio. Figure 5 compares the interdependency understanding items based on the type of tool used and provides strong support showing significant differences between the users of each type of tools for the ability of the tool to enable understanding of interdependencies, TUINT, and the ability to enable understanding of impact on other projects, TUIMP. These two measures provide support for H4(a) as they show highest mean responses for VPM users, followed by dependency matrix users, with the users of the tabular lists reporting the lowest levels of attention and understanding.

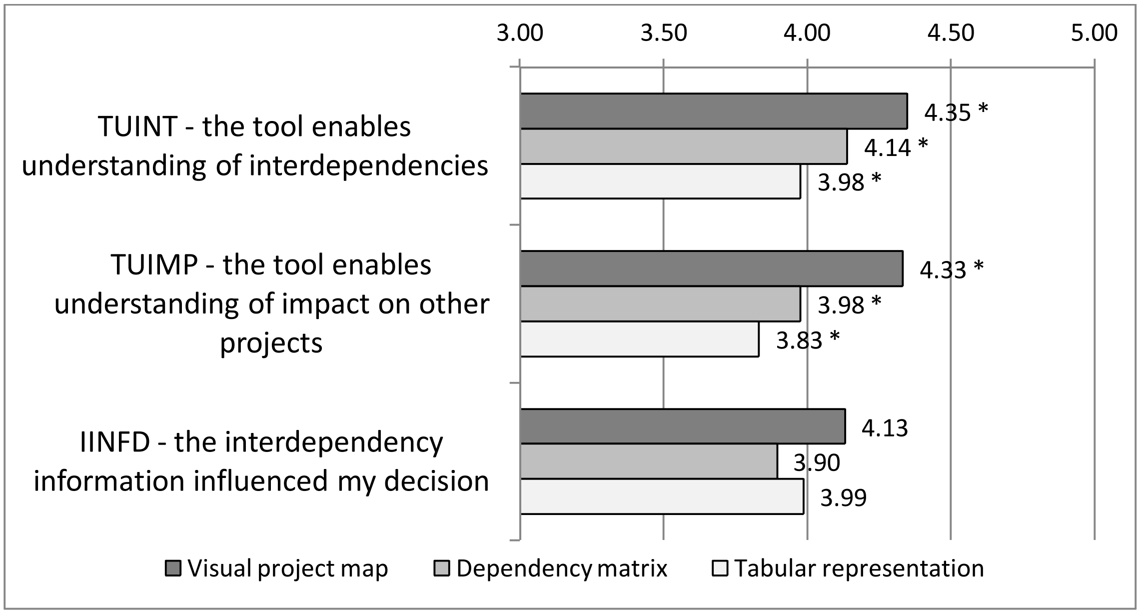

Figure 5: Mean responses on interdependency understanding and analysis by tool type (* indicates significance of 0.10 or better for differences between use and non-use of a tool).

Overall, these findings provide strong support for H4 and H4(a), indicating that the level of understanding of the interdependencies differs significantly between the different tools and is highest for users of VPM displays. However, although there are significant differences between each of the tools related to the levels of understanding of interdependencies and their impact on other projects as shown in Figure 5, there are no significant differences between the levels that the interdependency information influenced decisions, IINFD. This may explain the weaker decision quality results for the users of dependency matrices and tabular lists; when a weaker understanding of project interdependencies is used to influence decisions it will negatively affect the decision quality.

Hypothesis 5: Finally, as shown in Table B1 in Appendix B, all three measures of the understanding and analysis of interdependencies (TUINT, TUIMP and IINFD) show significant correlations with the quality of decisions as measured by DRATE, the decision quality rating (significance between 0.000 and 0.033), and the degree of confidence in the decision, CONF (at significance 0.000) providing strong support for H5.

SUMMARY AND CONCLUSION

An experiment-based study explored three different methods of representing project interdependency data and their relationships with decision quality in a simulated PPM decision scenario. The research proposed correlations between the use of different data representations and the level of understanding of project interdependencies and the resulting decision quality. VPM displays were proposed to have strongest correlations as they provide a direct visual representation of links between projects and of the 'web' of interdependencies in a complex portfolio.

The findings, based on a sample of 264 experiments, support and extend research that demonstrates the benefits of graphical data displays when compared with numerical and text-based information. The type of tool used to represent project interdependencies is correlated with differing levels of PPM decision quality (in support of H1). The use of VPM, the newly proposed network mapping approach, is correlated with the highest levels of decision quality indicating that the cognitive fit between the representation and the task may be strongest and that VPM has the potential to improve the quality of PPM decision making for complex project portfolios.

The importance of reducing time pressure in decision making is highlighted by the strong correlation between adequacy of time and improved decision quality (in support of H3), however no statistical difference was found in the perception of time adequacy between users of different tools (H2 was not supported).

The findings confirmed significant differences between tool type and the level of interdependency understanding and showed that users of VPM reported the highest levels of understanding (in support of H4). These findings provide further evidence that the VPM displays may have the strongest cognitive fit with the task of understanding interdependencies. Finally, the research reveals a very strong relationship between the level of understanding of the interdependencies and the decision quality (in support of H5). These findings show that the use of VPM is most strongly correlated with high levels of understanding of project interdependencies and of the flow-on effects of project decisions across the portfolio, and suggest that this understanding may contribute to higher decision quality.

Limitations and implications for future research: The experimental design outlined in this study illustrates how an experiment-based study can be useful in PM and PPM research, especially as a complement to organization-based research. There are limitations inherent in controlled experimentation that should be kept in mind, for example the results may be biased due to the design of the experiment or the fact that the use of students may not represent managerial decision making. In addition, the simplification of the scenario may skew the results and it is not known whether the inclusion of additional factors such as risk or project sponsorship levels would affect the findings. In addition, the management of interdependencies is more complex than illustrated in the scenario, and the method should be tested with multiple types or strengths of dependencies. Finally this research measured the decisions made by individuals and this may not accurately reflect group decision making which is central to PPM. Future experiments could test a different combination of factors and/or incorporate group decisions, and should aim to triangulate findings with organization-based research for improved validity and reliability.

Two aspects of the findings raise specific questions and suggest a need for further testing. First although the study showed a clear relationship between time and decision quality, none of the tools provided significant benefits through increased perceptions of time adequacy. Therefore more research is required to determine whether and how data representation methods can alleviate the time pressure and how they can be designed to efficiently enlist human cognitive capabilities in processing visual information. In addition, the findings suggest that the degree to which the interdependency information was used to influence the decision was not significantly affected by the differences between the levels of understanding reported. This misalignment could explain some of the lower quality decision outcomes, and could be investigated further to better understand the link between the level of understanding and the degree of application of that understanding to the problem.

Previous research on VPM conducted in organizational settings shows that organizational culture is an important factor in promoting information sharing and communication to support decision-making processes and tools (Killen and Kjaer, 2012). This experiment-based study did not explore such factors and although it was created to reflect decision challenges in organizations, such an experiment is not sufficient to draw conclusions about professional practice. However, as a complement to organization-based research, the experimental study has provided increased confidence in the findings through triangulation of the results. While the organizational study provided real-life experience and feedback on the use of VPM, due to the complexity of organizational environments it was not able to isolate the influence of VPM or to directly compare it with other methods. The research reported in this paper compensates for these limitations by using a controlled experimental setting where only one variable is adjusted (the type of data representation) and by analyzing and comparing the resulting decisions. The findings from the experimentation reinforce the findings from the organizational research; both show benefits from the use of VPM in improving understanding of project interdependencies. Experiment-based studies are not common in PM and PPM research, but show the potential to complement and augment organization-based studies. Researchers should consider extending and refining experiment-based approaches to enhance PM and PPM studies in the future.

Implications for management: The findings of this study highlight the importance of fit between the methods or tools employed and the problem at hand, mirroring findings from PPM research that demonstrate the need to tailor methods and tools to each situation. The use of visual data representations is supported, with the caveat that management should carefully consider the types of information required to support decisions and ensure that there is a good cognitive fit with the aspects of the data emphasized by visual data representations. With respect to the management of project interdependencies, the findings suggest that management should investigate whether visual displays, VPM in particular, can provide benefits in their organizations. The research supports the design and/or selection of software tools that create visual data displays to aid PPM decision making, especially highlighting the need for tools to manage interdependencies. In addition, the strong relationship between perceptions of time adequacy and improved decision quality supports efforts to reduce time pressure in decision environments. Managers should bear in mind that these results are based on a simulated decision task in a classroom setting that does not represent the full complexity of an organizational decision.

In conclusion, a controlled decision experiment has highlighted the influence of different data representations on PPM decisions. The study complements earlier organization-based research and provides a practical example of experimentation in project and portfolio management research. Network mapping data visualizations are found to be associated with higher levels of understanding of project interdependencies and better decision quality than the tabular or matrix-based data representation methods indicating that network mapping displays may have better cognitive fit with the task. These findings highlight the value of visual data representations, illustrate the value of designing data representations that are fit for the decision task, and suggest that network mapping data representations may have the potential to improve the quality of decisions in the management of complex project portfolios.

APPENDIX A

Table A1: Rated variables and survey items with descriptive statistics

Rating Label	Explanation of rated variable	Mean	Std. Deviation
CORR	Binary rating, 1 for correct or optimal decision, 0 for any other decision	0.17	0.377
DRATE	Rated decision on 5 point scale for the statement "The decision made balances the required criteria and represents an optimal decision"	2.80	1.475
Item Label	**Item statement for 5 point scale Likert response**	**Mean**	**Std. Deviation**
CONF	I am confident I have selected the best projects to eliminate	3.66	1.019
TTUT	Before the main task, I had enough time to understand the interdependency evaluation tool I was assigned	4.25	1.026
TTMD	I felt I had enough time to make this decision	3.77	1.182
TUINT	The tool that I used enabled me to understand the interdependencies between projects	4.16	.901
TUIMP	The tool I used enabled me to understand the impact of my decision on other projects in the portfolio	4.05	.955
IINFD	The interdependency information influenced my decision	4.01	1.072

Participants were presented with item scales anchored at the end- and mid-points for each of the items listed in Table A1. The following example illustrates the style of anchoring used in the data collection survey.

Item CONF: "I am confident I have selected the best projects to eliminate"

1	2	3	4	5
No, I am not at all confident I have selected the best projects		I think I probably selected an appropriate set of projects		Yes, I am very confident that the projects I selected are the best ones to eliminate

APPENDIX B

Table B1 outlines the correlations between items and the decision rating DRATE and the item CONF.

Table B1: Pearson correlations between decision quality measures and other items

	DRATE	CONF
TTUT	0.187 (sig 0.002)	0.323 (sig 0.000)
TTMD	0.224 (sig 0.000)	0.617 (sig 0.000)
TUINT	0.133 (sig 0.033)	0.288 (sig 0.000)
TUIMP	0.185 (sig 0.003)	0.445 (sig 0.000)
IINFD	0.226 (sig 0.000)	0.333 (sig 0.000)

References

Agor, Weston H., 1986, “The logic of intuition: How top executives make important decisions”. Organizational Dynamics, 14(3): 5–18.

Ahituv, Niv, Magid Igbaria and Aviem Sella, 1998, “The effects of time pressure and completeness of information on decision making”. Journal of Management Information Systems, 15(2): 153–172.

Anklam, P., R. Cross and V. Gulas, 2005, “Expanding the field of vision”. The Learning Organization, 12: 539–551.

Aritua, Bernard, Nigel J. Smith and Denise Bower, 2009, “Construction client multi-projects - A complex adaptive systems perspective”. International Journal of Project Management, 27: 72–79.

Archer, Norman P and Fereidoun Ghasemzadeh. 1999. "An integrated framework for project portfolio selection". International Journal of Project Management, 17: 207-16.

Arlt, Mario, 2011, "Application of experimental research to project portfolio management". The expanding domain of project research, International Network for Organising by Projects (IRNOP) Conference, Montreal.

Bendoly, Elliot and Morgan Swink, 2007, “Moderating effects of information access on project management behavior, performance and perceptions”. Journal of Operations Management, 25: 604–622.

Blau, Gary E., Joseph F. Pekny, Vishal A. Varma and Raul R. Bunch, 2004, “Managing a portfolio of interdependent new product candidates in the pharmaceutical industry”. Journal of Product Innovation Management, 21: 227–245.

Blichfeldt, Bodil Stilling and Pernille Eskerod. 2008. "Project portfolio management - There's more to it than what management enacts". International Journal of Project Management, 26: 357-65.

Borgatti, S., 2002, NetDraw: Graph Visualization Software. Harvard, MA: Analytic Technologies.

Bresciani, Sabrina and Martin J Eppler, 2010, "Choosing knowledge visualizations to augment cognition: the manager's view". Paper presented to the Information Visualisation (IV) 2010 14th International Conference on Information Visualisation, London, 2010.

Christiansen, J K and C Varnes, 2008, "From models to practice: Decision making at portfolio meetings". International Journal of Quality and Reliability Management, 25 (1), 87-101.

Cicmil, Svetlana, Terry Williams, Janice Thomas and Damian Hodgson, 2006, "Rethinking Project Management: Researching the actuality of projects". International Journal of Project Management, 24: 675–686.

Collis, Jill and Roger Hussey, 2003, Business Research: A Practical Guide for Undergraduate and Postgraduate Students New York: Palgrave Macmillan.

Collyer, Simon and C. M. J. Warren, 2009, "Project management approaches for dynamic environments". International Journal of Project Management, 27: 355–364.

Cooper, R. G., Scott J. Edgett and E. J. Kleinschmidt, 2001, "Portfolio management for new product development: Results of an industry best practices study". R and D Management, 31: 361–381.

Cross, Rob, Stephen P. Borgatti and Andrew Parker, 2002, "Making invisible work visible: Using social network analysis to support strategic collaboration". California Management Review, 44(2): 25–46.

Dane, Erik and Michael G. Pratt, 2007, "Exploring intuition and its role in managerial decision making". Academy of Management Review, 32: 33–54.

Danilovic, Mike and Tyson R. Browning, 2007, "Managing complex product development projects with design structure matrices and domain mapping matrices". International Journal of Project Management, 25: 300–314.

Dansereau, Donald F. and D. Dwayne Simpson, 2009, "A picture is worth a thousand words: The case for graphic representations". Professional Psychology: Research and Practice, 40: 104–110.

Dawidson, Ola. 2006. Project portfolio management – an organising perspective. PhD Thesis, Gothenburg, Sweden:: Chalmers University of Technology; 2006.

De Maio, A, R Verganti, and M Corso, 1994, "A multi-project management framework for new product development". European Journal of Operational Research, 78 (2), 178-191.

De Reyck, Bert, Yael Grushka-Cockayne, Martin Lockett, Sergio Ricardo Calderini, Marcio Moura and Andrew Sloper, 2005, "The impact of project portfolio management on information technology projects". International Journal of Project Management, 23: 524–537.

Dickinson, Michael W., Anna C. Thornton and Stephen Graves, 2001, “Technology Portfolio Management: Optimizing interdependent projects over multiple time periods”. IEEE Transactions on Engineering Management, 48: 518–527.

Dull, Richard B. and David P. Tegarden, 1999. “A Comparison of Three Visual Representations of Complex Multidimensional Accounting Information. Journal of Information Systems”, 13 (2): 117-131.

Durant-Law, Graham Alan, 2012, Network project management: Visualising collective knowledge to better understand and model a project-portfolio. Doctor of Philosophy Thesis, Faculty of Business and Government, The University of Canberra, Canberra.

Elonen, Suvi and Karlos A. Artto, 2003, “Problems in managing internal development projects in multi-project environments”. International Journal of Project Management, 21: 395–402.

Eskerod, P, B S Blichfeldt, and A S Toft, 2004, “Questioning the rational assumption underlying decision-making within project portfolio management literature”. PMI Research Conference, London, 11-14 July.

Floricel, Serghei and Mihai Ibanescu. 2008. "Using R&D portfolio management to deal with dynamic risk". R and D Management, 38: 452-67.

Foreman, E. and M. A. Selly, 2002, Decision by Objectives. Singapore: World Scientific Publishing Company.

Garson, G. David, 2012, Testing Statistical Assumptions. Asheboro, NC, USA: Statistical Associates Publishing.

Grossklags, Jen, 2007, “Experimental economics and experimental computer science: A survey”. Paper presented at the Workshop on Experimental Computer Science (ExpCS’07), ACM Federated Computer Research Conference (FCRC). San Diego, CA.

Hanneman, Robert A. and Mark Riddle, 2005, Introduction to social network methods. Riverside, CA University of California, Riverside (published in digital form at http://faculty.ucr.edu/~hanneman/).

Hansen, Derek, Ben Shneiderman and Marc A. Smith, 2011, Analyzing Social Media Networks with NodeXL: Insights from a Connected World. Amsterdam: Morgan Kaufman, Elsevier.

Hong, W., J.Thong, and K. Tam, 2004, “The effects of information format and shopping task on consumers' online shopping behavior: A cognitive fit perspective”. Journal of Management Information Systems, 21(3): 149 - 184.

Huang, Z., H. Chen, F. Guo, J. J. Xu, S. Wu and W-H. Chen, 2006, “Expertise visualization: An implementation and study based on cognitive fit theory”. Decision Support Systems, 42(2006): 1539-1557.

Janis, Irving L. and Leon Mann, 1977, Decision making: A psychological analysis of conflict, choice, and commitment. New York: Free Press.

Jonas, Daniel. 2010. "Empowering project portfolio managers: How management involvement impacts project portfolio management performance". International Journal of Project Management, 28: 818-31.

Kernbach, S. and Martin J. Eppler, 2010, “The use of visualization in the context of business strategies: An experimental evaluation”. Paper presented to the Information Visualisation (IV) 2010 14th International Conference on Information Visualisation, London, 2010.

Kester, Linda, Abbie Griffin, Erik Jan Hultink and Kristina Lauche. 2011. "Exploring Portfolio Decision-Making Processes". Journal of Product Innovation Management, 28: 641-61.

Kester, Linda, Erik Jan Hultink and Kristina Lauche. 2009. "Portfolio decision-making genres: A case study". Journal of Engineering and Technology Management, 26: 327-41.

Killen, Catherine P., Robert A. Hunt and E. J. Kleinschmidt, 2008, “Project portfolio management for product innovation”. International Journal of Quality and Reliability Management, 25(1): 24–38.

Killen, Catherine P. and Cai Kjaer, 2012, “Understanding project interdependencies: the role of visual representation, culture and process”. International Journal of Project Management, forthcoming. doi: 10.1016/j.ijproman.2012.01.018.

Killen, Catherine P., Brooke Krumbeck, Cai Kjaer and Graham Alan Durant-Law, 2009, “Managing project interdependencies: exploring new approaches”. Paper presented to the Asia Pacific Expert Seminar (APES2009): Managing Projects, Programs And Ventures In Times Of Uncertainty And Disruptive Change, Sydney, Australia, 2009.

Kim, Jongbae and Wilemon David, 2007, “The learning organization as facilitator of complex NPD projects”. Creativity & Innovation Management, 16(2): 176–191.

Levine, Harvey A., 2005, Project Portfolio Management: A Practical Guide to Selecting Projects, Managing Portfolios, and Maximizing Benefits. San Francisco, CA, Chichester: Jossey-Bass; John Wiley distributor.

Lovallo, D P and O Sibony, 2006, “Distortions and deceptions in strategic decisions”. McKinsey Quarterly, (1), 18-29.

Matheson, J E and M M Menke, 1994, “Using decision quality principles to balance your R&D portfolio”. Research Technology Management, 37 (3), 38-43.

Meyer, Alan D., 1991, “Visual data in organizational research”. Organization Science, 2: 218–236.

Mikkola, Juliana Hsuan, 2001, “Portfolio management of R&D projects: Implications for innovation management”. Technovation, 21: 423–435.

Perminova, O., M. Gustafsson and K. Wikström, 2008, “Defining uncertainty in projects: A new perspective”. International Journal of Project Management, 26: 73–79.

Petit, Yvan. 2011. "Project Portfolios in Dynamic Environments: Organizing for Uncertainty". The expanding domain of project research, International Network for Organising by Projects (IRNOP) Conference, Montreal.

Phaal, R, C J P Farrukh, and D R Probert, 2006, “Technology management tools: Concept, development and application”. Technovation, 26 (3), 336-344.

Platts, Ken and Kim Hua Tan, 2004, “Strategy visualisation: knowing, understanding, and formulating”. Management Decision, 42: 667–676.

Scott, John, 2008, Social Network Analysis: A Handbook. Thousand Oaks, CA: Sage Publications.

Shim, J.P., Merrill Warkentin, James F. Courtney, Daniel J. Power, Ramesh Sharda and Christer Carlsson, 2002, "Past, present, and future of decision support technology". Decision Support Systems, 33(2): 111–126.

Simon, Herbert Alexander, 1955, "A behavioral model of rational choice". Quarterly Journal of Economics, 69(1): 99–118.

Smelcer, J. B., and E. Carmel, 1997, "The Effectiveness of Different Representations for Managerial Problem Solving: Comparing Tables and Maps. Decision Sciences", 28(2): 391-420.

Svenson, Ola and A. John Maule (eds), 1993, Time Pressure and Stress in Human Judgment and Decision Making. New York: Plenum Press.

Tergan, S.-O. and T. Keller (eds), 2005, Knowledge and Information Visualisation. Berlin: Springer-Verlag.

Umanath, N.S. and Iris Vessey, 1995, "Multiattribute data presentation and human judgment: a cognitive fit perspective". Decision Sciences 25 (5,6): 795-824.

Verma, Devesh and Kingshuk K Sinha, 2002, "Toward a theory of project interdependencies in high tech R&D environments". Journal of Operations Management, 20: 451–468.

Vessey, Iris, 1991, "Cognitive fit: a theory-based analysis of the graphs versus tables literature." Decision Sciences, 22(2): 219-41.

Warglien, Massimo, 2010, "Seeing, thinking and deciding: some research questions on strategy and vision". Paper presented to the Academy of Management Meeting, August 6th, Montreal.

Warglien, Massimo and Michael G. Jacobides, 2010, "The power of representations: From visualization, maps and categories to dynamic tools". Paper presented to the Academy of Management Meeting, August 6th, Montreal.

Williams, Terry, 2005, "Assessing and building on project management theory in the light of badly over-run projects". IEEE Transactions on Engineering Management, 52: 497–508.