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Evaluation of project interdependency visualizations through decision scenario experimentation

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Abstract

The interdependence between projects in complex portfolios sharpens the challenge of project portfolio decision making. Methods that assist with the evaluation of data can address decision challenges such as information overload and time pressure. A decision simulation in a controlled experiment explored the use of visual representations of project interdependency data to support project portfolio decision making. Dependency matrices and network mapping were compared with non-graphical lists of dependency data. The findings show that the type of tool used may influence the quality of the resulting decision. Using visual tools, particularly network mapping displays, is correlated with the best results.

The research provides a practical example of experimentation in project and portfolio management research and illustrates how such studies can complement organization-based research. Findings of interest to management include the importance of ensuring adequate time for decision processes and the potential benefits from using visual representations of project interdependence.

Introduction

Project portfolio management (PPM) is 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. Project portfolio decisions require managers to analyze a variety of information in limited time. These portfolio-level decisions affect the success of the portfolio by ensuring resource adequacy, dynamic agility, and strategic alignment using a portfolio-level rather than a project-level perspective (Floricel and Ibanescu, 2008; Petit, 2011). 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 tools and methods to collate and analyze project data (Cooper *et al.*, 2001; De Reyck *et al.*, 2005; Kester *et al.*, 2011).

Portfolios of complex and interdependent projects are particularly challenging for decision makers and there is an identified need for better tools to understand and manage project interdependencies. 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). Case studies and action research are commonly used to test the application of new tools or methods for project management or PPM. 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. Organizational research settings do not provide a reliable and static environment where it is possible generalize findings by testing the effects of changes in a systematic method in an experimental fashion.

This paper outlines the use of controlled experimentation in a classroom setting to test the ability of visual data representations of project interdependencies to support PPM decision making. The ultimate aim of the research is to develop understanding of the relevant factors and tools to improve decision quality. The research reported in this paper also provides an example of the use of experimental decision simulations for PPM research and explores what can be learned from such experimental studies.

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. By managing project investments from a portfolio level and allowing opportunities for new projects to be considered along with decisions about whether to continue investing in existing projects, PPM provides a high-level strategic perspective that enables organizations to identify and respond to trends and opportunities. PPM decisions require consideration of multiple factors and the ability to envision alternative future consequences of project decisions across a portfolio.

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 PRB usually consists of experienced managers who represent the breadth of functions or divisions affected by portfolio decisions. PPM activities include the collection, collation, and presentation of up-to-date information on the existing and proposed projects to inform PRB decision making. Managing a portfolio of projects represents a complex multi-dimensional decision challenge. Information on aspects such as strategic alignment, financial projections, project status, market trends, the availability of skills and resources, and sources and levels of risk must be considered and balanced across the portfolio (De Reyck *et al.*, 2005; Levine, 2005). Visual representations of data, such as 2x2 risk-reward portfolio maps, are regularly used to support PRB discussions and balancing decisions (Mikkola, 2001). The use of such visual data representations is correlated with better portfolio performance (Cooper *et al.*, 2001: Killen *et al.*, 2008).

The challenge of managing a portfolio of projects is amplified by the presence of interdependencies (Perminova *et al.*, 2008; Collyer and Warren, 2009). 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; Rungi, 2007). Many PPM tools and methods, while providing a portfolio-level perspective for balancing project decisions, still treat each project as an isolated entity. Projects are said to be interdependent when the success of a project depends upon another project. A portfolio-level perspective is required to reveal such inter-project effects; however, these effects can be complex and difficult to predict (Aritua *et al.*, 2009).

As PPM matures and project complexity and interdependency increase, it is no longer sufficient to apply traditional PPM tools that consider projects as independent of each other. PPM processes and tools exist to help managers identify the dependencies so they can make project decisions with the understanding of the possible flow-on effects to other projects in the portfolio (Shenhar *et al.*, 2001). Interdependencies are often identified in project databases and dependency matrices. Dependency matrices allow interdependencies to be visualized on a two-dimensional grid that displays dependencies between each pair of projects in a portfolio (Dickinson *et al.*, 2001; Danilovic and Browning, 2007). Such tools are limited to dependency pairs and do not readily illustrate multi-step dependencies. For example, when a first project is dependent on a second project that in turn is dependent upon a third project, a dependency matrix does not identify a relationship between the first and third projects. The management of interdependences is acknowledged as an area of weakness for PPM (Elonen and Artto, 2003). 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

Management decisions such as PPM decisions must often be made by considering multiple criteria and large amounts of data. However, humans are subject to 'bounded rationality', which limits their ability to interpret data and make rational decisions (Simon, 1955). According to the bounded rationality concept, three elements affect decision-making capability: the lack of complete and accurate information, the human cognitive limitations in interpreting the information, and the finite amount of time available to make decisions. All three of these elements contribute to the challenge of PPM decision making, especially in complex and dynamic environments.

The need for compete and up-to-date information to inform decision making is one of the primary drivers of PPM implementation. Data completeness and accuracy present a constant challenge, especially in dynamic environments or where projects are diverse in type, region, or sponsorship. PPM aims to provide a holistic and consistent framework for PPM decisions that enables data to be collected and presented uniformly. However, it is difficult to obtain complete and accurate data and to present all of the possible information. Therefore

PPM approaches aim to filter and present the data in a manner that highlights the most important information.

Most PPM decisions involve human judgment, often in a PRB where each individual's experience, diversity, and judgment contributes to a powerful team perspective for decision making. However, human decision makers work within cognitive limits. Experiments have revealed the limitations in human capability to recognize interdependencies and resultant flow-on effects from their decisions and actions in complex systems (Doerner, 1989). Complex and critical decisions are particularly affected by human cognitive constraints (Foreman and Selly, 2002). While human capabilities are limited, research suggests that visualization techniques can compensate for limitations in working memories and extend both the capacity and the duration of stored information (Tergan and Keller, 2005).

Time pressures compound the challenges associated with human cognitive limitations. Increasing volumes of information must be absorbed to support decision making (Shim *et al.*, 2002), and the amount of time available for managers to digest and analyze the information is often limited (Agor, 1986; Dane and Pratt, 2007). Time pressure is associated with impaired decision quality (Ahituv *et al.*, 1998) and a lack of depth in the evaluation of alternatives (Janis and Mann, 1977; Svenson and Maule, 1993). Project management research identifies time constraints as a factor contributing to project over-runs (Williams, 2005; Cicmil *et al.*, 2006).

Therefore, due to bounded rationality's triad of incomplete information, limited cognitive capabilities, and limited time, PPM decisions may not be optimal (Blichfeldt and Eskerod, 2008). A variety of PPM activities aim to alleviate one or more of these challenges to improve decisions. For example, data analyzed at PPM meetings are usually first filtered and formatted, ideally in a way that will be useful in the time available and within human cognitive limits. The composition and management of the PRB is also important, and much attention has been paid to methods for selecting PRB team members. In addition, methods that facilitate PRB members' ability to interact and discuss issues are proposed to balance individual bias and compensate for individual limitations (Cooper *et al.*, 2001; Levine, 2005; Maizlish and Handler, 2005).

The rise in computer applications and power has also generated research into computer-based methods to aid managers in evaluating information and improving decision making. Many forms of computer-based decision support systems have been suggested, with the aim of making decision making more efficient 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. Software solutions with integrated team collaboration capabilities show more potential, as they are designed to satisfy the need for manager input and interaction (Marcus and Coleman, 2007).

Visual representations and decision making

Graphical methods of displaying and evaluating data are often useful in management environments as they provide an efficient alternative method for visualizing and analyzing complex data (Mikkola, 2001) and for helping to 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).

To best analyze and evaluate PPM data for decision making, the combination of human analytical skills with tailored visual representations of data holds great promise. The creation and analysis of visual data representations bring together the power of computing with the benefits of PRB team experience and judgment. Improvements in computers and software-based tools have greatly enhanced the ease of creating visual representations, and new ways of collecting and displaying data facilitate new types of visualizations (Dansereau and Simpson, 2009). Computer-based tools with visual interfaces, paired with flexible human cognitive capabilities such as pattern finding, combine the benefits of both and may be the most powerful and flexible cognitive systems (Tergan and Keller, 2005).

Portfolio maps are an established PPM tool that is one of a variety of visual representations of knowledge commonly used in PRB team decision making. Research is beginning to examine how visual knowledge displays are used in decision-making environments and to shed light on which types of displays best support decision making in specific environments; however, there is a need for more research in this area (Warglien and Jacobides, 2010). Visual representations of knowledge often need to display multiple factors, capture historical events, and reveal complex relationships to support decision making (Platts and Tan, 2004). One study found that 2x2 matrix displays, like those used in portfolio maps, supported decision making and had particular strengths in evaluating and sharing information (Bresciani and Eppler, 2010). These 2x2 matrices are able to present multiple types of information in '2½-dimensional' displays that are very powerful if well designed (Warglien, 2010). Research has shown correlations between the use of portfolio maps and better PPM outcomes (Cooper *et al.*, 2001; Killen *et al.*, 2008) and a number of existing software solutions aid in the creation of such displays.

Network maps as a visual PPM tool

While portfolio maps show benefits when applied in PPM, they have limitations in that they do not show the relationships between projects. Network maps, on the other hand, are ideally suited for illustrating relationships between projects in a portfolio. Network maps visually display relationships between nodes in a network and reveal accumulated network effects (Scott, 2008). Network maps are usually created by software-based tools that help to record, analyze, and graphically display the relationships. Such maps facilitate enhanced analyses through modeling of existing networks or proposed changes in an intuitive and easy-to-interpret format that can help reveal patterns more clearly than verbal explanations or matrix displays of data (Hanneman and Riddle, 2005).

Network mapping is used to support many types of management decisions; however, such displays are not currently applied in PPM decision-making environments. Existing applications of network mapping include mathematical, biological, and economic modeling (Hanneman and Riddle, 2005). Social network analysis (SNA) is one of the most common applications of network mapping where relationships between people or organizations are presented and analyzed in a visual form (Cross *et al.*, 2002; Anklam *et al.*, 2005; Scott, 2008). Network mapping has also been used in conjunction with design structure matrix tools to manage interdependencies between tasks in product development environments (Bradley and Yassine, 2006; Collins *et al.*, 2009).

The wide applicability of network mapping to support data analysis and decision making, and its particular strengths in illustrating relationships between elements, have led to investigations of its use to support the analysis of project interdependencies in PPM (Killen *et al.*, 2009; Killen and Kjaer, 2012). A 'visual project map' (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.

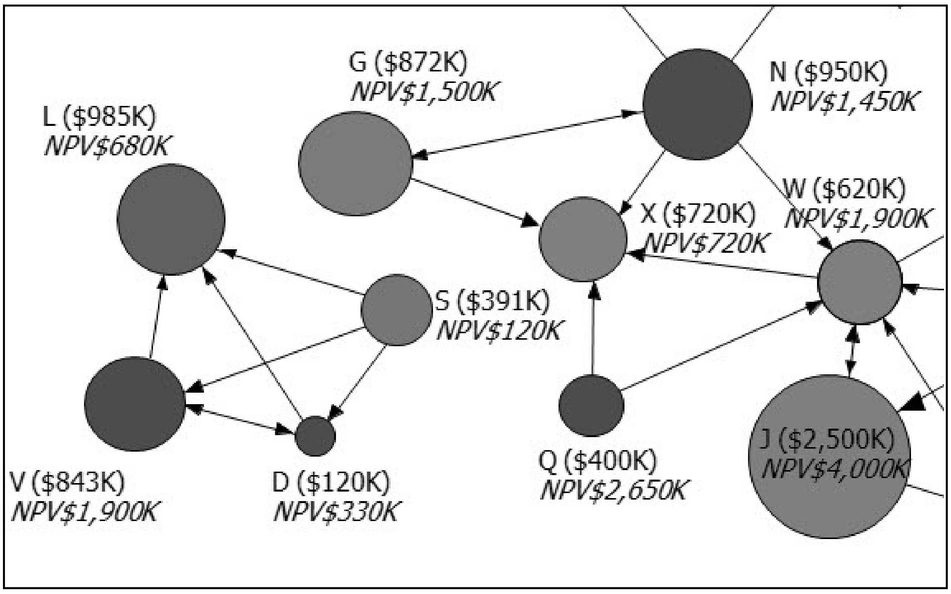

Figure 1: Portion of a visual project map (VPM). Labels provide project name (letter), investment required and NPV. Circle size reflects investment required.

The use of network maps for PPM is a new application that has shown benefits as a decision-making or communication tool for PPM in initial trials in two organizations (Killen and Kjaer, 2012) and an application in a defense portfolio showed that it can be useful for project, program, and portfolio management (Durant-Law, 2012). Although these early studies showed promise for VPM as an aid to PPM decision making, these results have been conducted in a limited number of portfolios in diverse organizational settings. Therefore it is difficult to generalize findings or to isolate the effects of introducing VPM displays from the influence of other organizational variables. These findings suggest that further studies are needed to determine whether, or how, VPM can improve the analysis of project interdependencies for effective PPM.

Finally, although this paper focuses on tools for visualizing data, it should be highlighted that PPM is not only a matter of tools and methods. Organizational culture is an important factor that must support communication and complement tools and methods for best results (Williams, 2007). Research repeatedly indicates a high correlation between successful PPM performance, high levels of top management support, and a culture that promotes information sharing and transparency (Cooper *et al.*, 2001; Kim and David, 2007; Killen *et al.*, 2008; Jonas, 2010). A high level of trust between portfolio managers and project managers, and the creation of a culture that encourages and facilitates regular information sharing among project teams, are essential in complex and dynamic project environments (Aritua *et al.*, 2009). A better understanding of project interdependencies has been shown to be correlated with an organizational culture that facilitates the capture and sharing of information and supports between-project communication (Killen and Kjaer, 2012).

In summary, the multi-factor challenge faced by PPM decision makers continues to become more demanding as project environments become more complex and interconnected. Bounded rationality affects decision making as information is not always complete, humans have limited cognitive capability, and decision making is often done under time pressure. Organizational culture and communication also affect decision making, and some tools can aid communication. PPM decisions are often made in meetings and aided by visual tools to represent data and facilitate discussions of the data. These tools may compensate for human cognitive limitations and reduce the influence of bounded rationality on decision making. The use of portfolio maps as a PPM tool is correlated with improved PPM performance; however, these 2x2 matrix displays do not assist with the evaluation of project interdependencies that is especially important as portfolios become larger and more complex. Dependency matrices are a matrix-based method used to display and manage project interdependencies and VPM is a new network mapping-based method that showed promise in early research. Further research is needed to understand whether and how these visual tools contribute to PPM decisions.

Research hypotheses

In an increasingly complex project landscape, the literature highlights the particular challenge presented by project interdependencies and the inadequacy of current methods to support PPM decision making. The correlation between the use of portfolio maps and PPM outcomes illustrates how visual tools can assist with PPM decision making. This research project examined the impact of using visual and non-visual methods to evaluate interdependency data to support decision making in complex project portfolios. The methods under investigation were (1) VPM – a graphical network mapping display, (2) Dependency matrices – a graphical matrix display and (3) Tabular list – a text-based (non-graphical) list of dependencies in a table.

This study aimed to determine whether and how tools for evaluating project interdependencies can assist with PPM decision making. Visual displays such as VPM and dependency matrices are proposed to provide advantages when combined with human cognitive capabilities during decision making (Tergan and Keller, 2005). VPM, with an ability to directly reveal multi-step dependencies that is lacking in dependency matrices, are proposed to contribute most strongly to decision quality.

Therefore, the first hypothesis addressed in this study is:

H1: The type of tool used to evaluate project interdependencies will have an effect on the quality of the resulting PPM decisions in complex project portfolios.

H1(a): The use of visual data representations (dependency matrices and VPM displays) will improve the quality of PPM decisions in complex project portfolios.

H1(b): VPM displays will contribute to better quality PPM decisions than the other tools in complex project portfolios.

The literature suggests that time pressures may 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. 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. As visual displays allow data to be cognitively processed while preserving spatial orientations and interrelationships (Meyer, 1991), it is proposed that the visual tools (VPM and dependency matrices) will provide time saving benefits in the analysis of interdependencies. The second and third hypotheses are:

H2: Perception of time adequacy positively relates to the quality of the resulting decision.

H3: Users of visual displays will be less likely to feel time pressure during decision making than users of non-graphical tools.

Human cognitive capabilities will be most powerful when the decision maker is engaged in a task and actively thinks about the problem, as they will be focusing their cognitive capabilities to the task. In addition, when decision makers analyze and apply information obtained visually to the decision problem, they are working in a potentially powerful cognitive system. These types of decision task engagement and analysis activities are proposed to be an important component in an effective decision process. Therefore the fourth hypothesis is:

H4: Level of engagement and analysis positively relates to the quality of the decision.

H4(a): Users of visual displays will report higher levels of engagement and analysis during decision making than users of non-graphical tools.

A controlled decision scenario experiment was used to measure decision quality, time pressure, and levels of engagement and analysis to test these hypotheses as outlined in the following section.

Research method

Methodology

The research design involved the creation of a simulated decision task in a controlled classroom setting and a survey of the research participants to record the resultant decisions and collect data on a number of items. Human subject experimentation is often found in fields like psychology, economics, or marketing; however, this type of method is not common in project management or PPM research. This research provides valuable experience in the application of experimentation to project-related research. Earlier studies in this area 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). Decision making in product development environments has also been explored experimentally (Schmidt and Calantone, 2002; Spanjol *et al.*, 2011).

Experimentation has advantages that can complement the more prevalent organization-based case studies or action research 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.

The experiment evaluated and compared the use three different methods of presenting project interdependency data. The control group did not use a visual data representation tool; project interdependency data were supplied only in a tabular list (text in a table). The other two groups were provided interdependency data presented in one of two visual data representation tools. The tools used were the dependency matrix (a tool currently used in some organizations) and VPM (visual or graphical project mapping, the new method under investigation). By comparing the decisions made based on identical data but using different methods to represent the interdependency data, the experiment was designed to highlight any differences that might be a result of the type of data representation tool. The study also collected and analyzed responses on other items such as the level of confidence in the decision, perceptions about whether the tool helped reveal interdependencies, and perceptions about whether the time allowed was adequate for the task.

Students are often used as research subjects in experimental research, sometimes as volunteers outside a classroom environment (Arlt, 2011), and other times as part of a unit of study (Bendoly and Swink, 2007). Although it would be preferable to use practicing managers in research experiments involving management decisions, it is difficult to access large numbers of professionals for such research. Students are easier to access and can be suitable contributors to such research if selected appropriately. The study reported in this paper involved students in a postgraduate coursework unit conducted by the Faculty of Engineering and Information Technology at the University of Technology, Sydney. The unit, Technology and Innovation Management, is taken by students in the Master of Engineering Management and Master of Engineering programs. The students in this course were considered suitable for such a study as they have completed an engineering or technical undergraduate degree and are already familiar with project management concepts, and therefore possess a similar educational background to many project portfolio managers. 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.

The use of students as research subjects had another advantage. It was felt that the experiment would be of interest to the students and that it would augment and extend their education. The educational aspect was an important consideration for an experiment that would be conducted during a class session. As part of the course, the students learn about methods to combine quantitative and qualitative data in order to make decisions about innovation projects. Before the experiment, the students had already been exposed to PPM concepts and had developed experience using visual tools such as portfolio maps and pie charts to aid decision making. The research task augmented the educational aspects of the course by introducing the concept of project interdependency management, introducing tools for the management of interdependencies, and providing an opportunity to experience applying such tools.

As this research involved students, the university ethics clearance process was followed and approval was granted. The research was conducted so that participation was voluntary and confidential; the individual names of participants were not collected or revealed in any way. One week before the experiment, students were informed in the lecture and by email about the upcoming experiment in class. The lecturer outlined the overall research intent and process, and the ethical requirements. This information was repeated again directly before the experiment. The students were asked to provide informed consent to participate in the research or to elect to perform an alternative task that would enable them to gain similar educational outcomes. The alternative task was very similar to the research task but did not include data collection. Students were assured that there was no penalty or disadvantage if they elected the alternative task; however, no student chose the alternative option. All of the students provided their informed consent to participate in the research.

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.

Experiment session detail

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 very short survey.

A decision scenario was developed for the class session. The students were given data on 26 fictional projects in a complex portfolio worth several million dollars. The decision scenario was designed to represent 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.

As part of the educational session leading up to the decision task, project portfolio concepts were reviewed, the management of project interdependencies was introduced, and the three tools being tested in the experimentation session were overviewed. The experiment was then introduced and students were again provided with information on the purpose and nature of the experiment, the ethics guidelines, and the voluntary nature of the experiment.

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 the tools. Students were given time to read their individual instructions and to perform a small exercise to test their understanding of their allocated tool (the control group performed the exercise reviewing dependency data in the tabular format only). The results of this warm-up task were reviewed in class and any questions were addressed individually to help the students learn how to interpret and use their assigned tool.

Students in each group were then asked to review identical project data for the decision scenario. The data for the 26 projects in the portfolio included investment and net present value projections, a rating for degree of strategic fit, and information on project interdependencies. A project was described as dependent on another project if it required something from that project in order to successfully meet goals. For simplicity, all dependencies were assumed to be equal; varying types and strengths of project interdependency 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 balance the following three considerations when trimming the portfolio budget by ten per cent:

1. Consider flow-on effects on dependent projects and avoid cancelling projects that other projects depend upon (especially strategically important or highly profitable projects).
2. Consider the strategic fit of the projects in the portfolio and try not to remove strategically important projects.
3. Consider the return on investment of the portfolio and try not to remove highly profitable projects.

The experiment was terminated after 15 minutes and students were asked to finalize and record their decision and complete the short confidential survey.

Survey and item development

The survey recorded the tool used and the decision made, and gathered information on the respondent's experience using the tool and participating in the experiment, including their confidence in their decision, and their perception of the adequacy of the time allocated, the degree of attention the task required, and the ability of the tool to assist with analysis of dependencies.

Table 1 outlines the items that were designed to test the hypotheses. Items 1 and 2 in Table 1 were calculated based on the decision entered by the participant. Items 3-10 in Table 1 employed anchored Likert scales to collect responses. The scales were anchored at the end- and mid-points. The following two examples illustrate the style of anchoring used throughout the survey.

"I felt I had enough time to make this decision"

1	2	3	4	5
No, I did not have even close to enough time		The time was just barely adequate		Yes, I had plenty of time to make this decision

"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

H1: The type of tool used to evaluate project interdependencies will have an effect on the quality of the resulting PPM decisions in complex project portfolios.

Decision quality is determined through three measures: a binary rating of whether the respondents selected the correct decision (CORR, no. 1 in Table 1), a scaled rating of the decision quality (DRATE, no.2 in Table 1), and through an item in the survey to assess participants' confidence in their decision (CONF, no. 3 in Table 1). The scenario was designed so that there was one decision (a particular combination of projects to cancel) that best met the decision requirements and constraints; this was the optimal or correct decision. The variable CORR was created with a value of 1 for the correct decision, and 0 for any other decision. The decision quality (DRATE) was rated on a scale of 1–5, 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. The scaled decision quality rating (DRATE) followed the format:

"The decision made balances the required criteria and represents an optimal decision"

1	2	3	4	5
No, the decision does not appear to meet any of the criteria		The decision incorporates some of the criteria but is not balanced		Yes, the decision is the best possible to meet and balance the criteria

Perception-based responses are often used in survey research and are reliable indicators of reality. As the rating of the decision could be subjected to bias during the rating process, the addition of a perception-based item (no. 3 in Table 1) on participants' confidence in their decision provided an extra degree of reliability. These three decision-quality ratings were correlated with tool type to address H1.

H2: Perception of time adequacy positively relates to the quality of the resulting decision

H3: Users of visual displays will be less likely to feel time pressure during decision making than users of non-graphical tools.

Item numbers 4 and 5 in Table 1 collected the research participants' perceptions of time adequacy. All participants were allowed the same amount of time to complete the decision task so differences in responses may reveal whether certain tools are correlated with better perceptions of the adequacy of the time available (the opposite of perceptions of time pressure). The items asked for perceptions about whether there was enough time to understand the tool (an indication of how easy or quick the tool was to learn or implement) and whether there was enough time to make the decision (an indication of whether the tool enabled the data to be evaluated within the limited time period). Findings from these items were correlated with decision quality measures and tool type to address H2 and H3.

H4: Level of engagement and analysis positively relates to the quality of the decision.

A series of items assessed whether the decision task required attention or caused participants to think (items 6 and 7 in Table 1), whether the tool used was instrumental in the understanding of project interdependencies and portfolio effects of decisions (items 8 and 9), and whether the interdependency information influenced the decision made (item 10). Findings from these items are correlated with decision quality measures and tool type to address H4.

Data collection and analysis

The experimentation was conducted in three sections of the postgraduate subject Technology and Innovation Management during October 2011, and resulted in 104 valid survey responses from 108 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. Mean and standard deviations for the survey items are presented in Table 1.

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, 2006). 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 three pairs representing all combinations of two of the three classes. No significant differences were found between 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.

Table 1: Rated variables and survey items with descriptive statistics

Rating no.	Label	Explanation of rated variable	Mean	Std. Deviation
1	CORR	Binary rating, 1 for correct or optimal decision, 0 for any other decision	0.27	0.446
2	DRATE	Rated decision on 5 point scale for the statement "The decision made balances the required criteria and represents an optimal decision"	3.02	1.455
Item no.	**Label**	**Item statement for 5 point scale Likert response**	**Mean**	**Std. Deviation**
3	CONF	I am confident I have selected the best projects to eliminate	3.63	1.005
4	TTUT	Before the main task, I had enough time to understand the interdependency evaluation tool I was assigned	4.20	1.083
5	TTMD	I felt I had enough time to make this decision	3.60	1.219
6	ATT	My attention was focused on the decision task	3.89	.847
7	THINK	The decision task caused me to think	4.15	.890
8	TUINT	The tool that I used enabled me to understand the interdependencies between projects	4.18	.916
9	TUIMP	The tool I used enabled me to understand the impact of my decision on other projects in the portfolio	4.12	.915
10	IINFD	The interdependency information influenced my decision	4.09	1.034

Findings and discussion

Hypothesis 1: To address H1, that decision quality will relate to the type of tool used to evaluate project interdependencies, the three measures of decision quality were compared based on the type of tool used. The binary variable CORR was created based on the answers submitted on the 104 surveys. Overall, 26.9 per cent of respondents arrived at the correct and optimal decision during the decision task. As shown in Figure 2, the percentage of research participants that made the optimal decision was highest for the group that used the visual VPM tool, with more than one-third of the participants achieving an optimal decision in the time allowed. Just over one-quarter of the decisions made using the other visual tool, the dependency matrix, were optimal. The performance was lowest for the control group, those that did not use a visual data representation and had to evaluate the project interdependencies from data in a tabular form. These results, including the finding that VPM resulted in the highest percentage of correct decisions, provide initial support for hypotheses 1, 1(a), and 1(b).

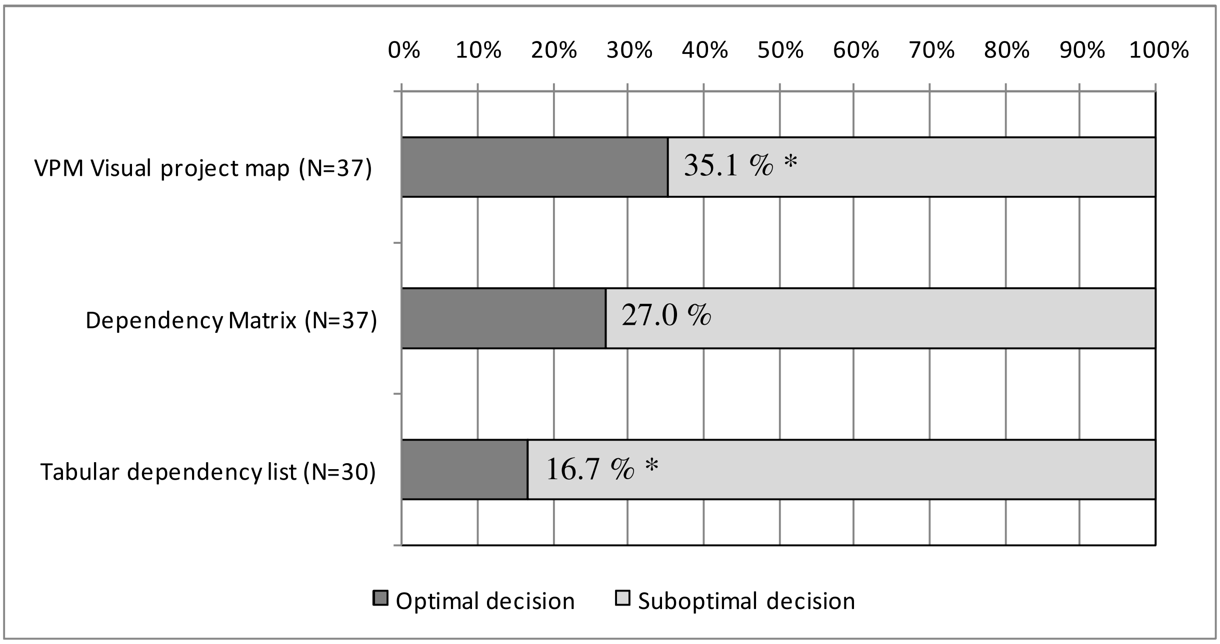

Figure 2: Percentage of optimal decisions (CORR=1) per tool type (* = indicates 0.10 or better significance of the difference between use and non-use of a tool)

Figure 3 provides an alternative view using the rated degree of decision quality. Ratings were assigned to each decision for the variable DRATE (rated degree of decision quality) according to the rating scale described above. Overall, the mean value for DRATE was 3.02 with a standard deviation of 1.455. Figure 3 illustrates the mean values for DRATE for groups using each tool. As would be expected, the two measures of the quality of the decision, CORR and DRATE are highly related. The mean value of DRATE for respondents where CORR=0 (not the optimal decision) is 2.4 whereas the mean value for DRATE when CORR=1 is 5.0 (mean difference of 2.6, sig 0.000).

These results support hypotheses 1, 1(a), and 1(b). Statistically significant support for H1(b) shows that the use of the VPM tool resulted in the highest values for DRATE, with a mean improvement in the decision rating of 0.725 compared with users that do not use VPM (sig 0.014). The use of tabular representations resulted in the lowest values for DRATE, with a mean decrease in the decision rating of 0.495 compared with the users of the two visual tools, VPM and dependency matrices, providing support for H1(a).

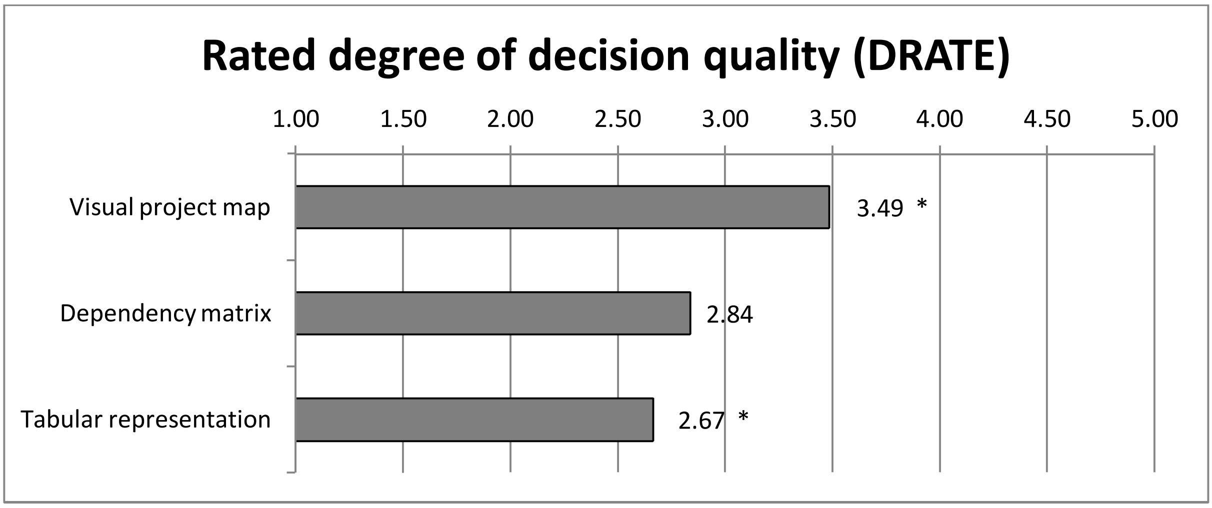

Figure 3: mean rating for decision quality per tool type (* indicates 0.10 or better significance of the difference between use and non-use of a tool).

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 0.377, sig .000).

Overall, these findings support H1, H1(a), and H1(b). The type of tool used to evaluate project interdependencies correlated with differing levels of decision quality, and the use of visual data representations (dependency matrices and VPM displays) corresponded with better decisions than the non-graphical tabular list. In addition, as proposed, VPM displays corresponded with the best decision quality results.

Hypotheses 2 and 3: H2 proposed that perceptions of time adequacy would positively relate to decision quality. As shown in Table 2, 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.

Table 2: Adequacy of time correlated with decision quality measures (all correlations significant at 0.01 or better)

	DRATE - decision rating	CONF - confidence in decision
TTUT - I had enough time to understand the tool Pearson Correlation	**0.306 (sig 0.002)**	**0.389 (sig 0.000)**
TTMD - I had enough time to make the decision Pearson Correlation	**0.300 (sig 0.002)**	**0.639 (sig 0.000)**

H3 proposed that users of visual tools would feel less time pressure. Comparison of the perceptions of time adequacy with type of tool used did not reveal any relationships strong enough to statistically support H3.

Hypothesis 4: H4 proposed that the level of engagement and analysis will positively relate to the quality of the decision. As shown in Table 3, four of the five items used to measure engagement and analysis correlated with the quality of decisions as measured by DRATE, the decision quality rating (significance between 0.022 and 0.075), and the degree of confidence in the decision, CONF (significance between 0.000 and 0.007). With the exception of the item THINK, measuring how much the task caused the research participant to think, the data provide strong support for H4.

Table 3: Engagement and analysis correlated with decision quality measures (bold correlations significant at 0.10 or better)

	DRATE - decision rating	CONF - confidence in decision
ATT - my attention was focused on the task Pearson Correlation	**0.175 (sig 0.075)**	**0.262 (sig 0.007)**
THINK - the task caused me to think Pearson Correlation	0.041 (sig 0.679)	0.069 (sig 0.489)
TUINT - the tool enables understanding of interdependencies Pearson Correlation	**0.180 (sig 0.071)**	**0.306 (sig 0.002)**
TUIMP - the tool enables understanding of impact on other projects Pearson Correlation	**0.227 (sig 0.022)**	**0.435 (sig 0.000)**
IINFD - the interdependency information influenced my decision Pearson Correlation	**0.231 (sig 0.018)**	**0.301 (sig 0.002)**

Figure 4 compares the engagement and analysis items based on the type of tool used to determine whether H4(a) is satisfied. The findings are mixed. Two of the engagement and analysis items show weak indications that the users of visual displays may experience higher levels of engagement and analysis during decision making than users of non-graphical tools. The level of attention reported, ATT, and the ability of the tool to enable understanding of interdependencies, TUINT, showed 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.

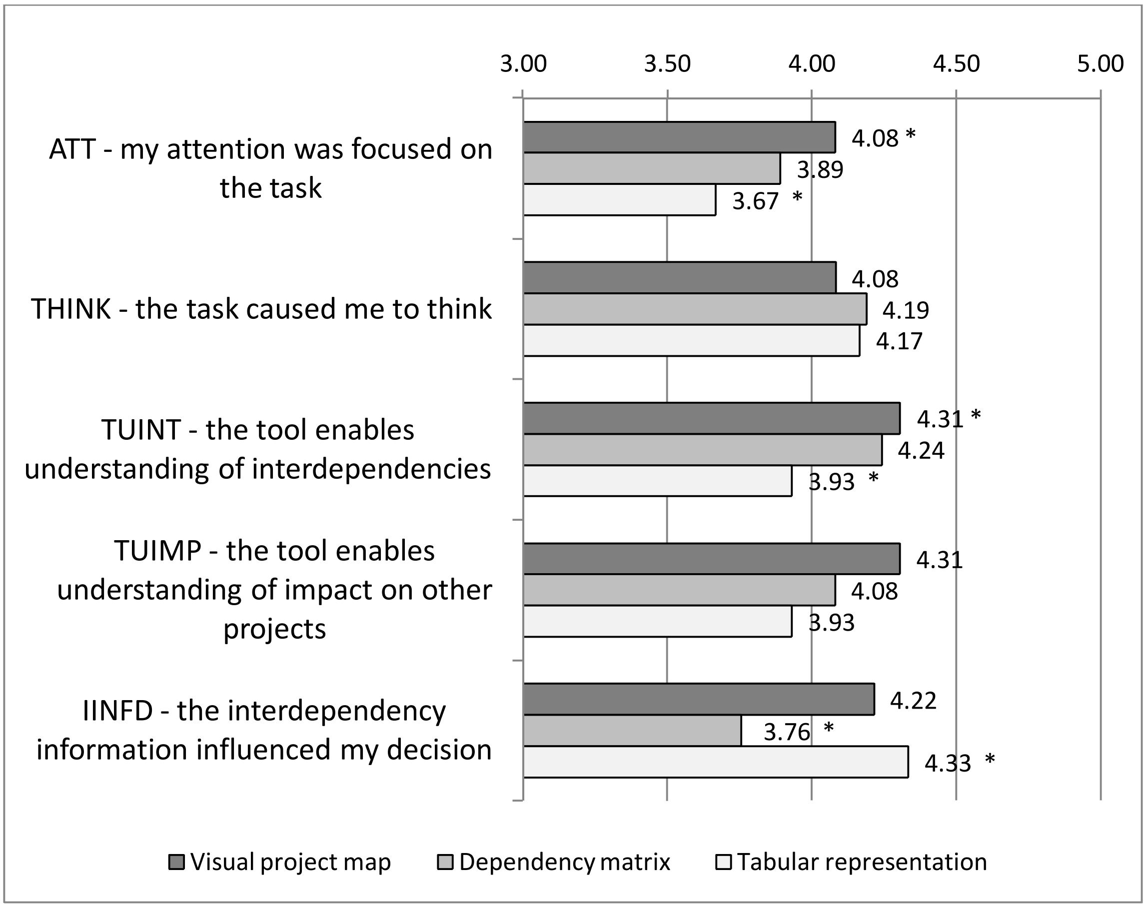

Figure 4: Mean responses on engagement and analysis by tool type (* indicates significance of 0.10 or better for differences between use and non-use of a tool).

Interestingly, as shown in Figure 4, although users of tabular lists reported the lowest responses for the ability of the tool to help them understand interdependencies, TUINT, and the impact of decisions on other projects, TUIMP, these users reported the highest response on the level that the interdependency information influenced their decisions, IINFD. This suggests an example of bounded rationality in decision making. The responses indicate that the decisions made by the users of the tabular lists may have been made on a less rational basis than by users of other tools: although their understanding of the information was weaker, that same information had a larger influence their decision. This finding may explain why the decision quality was lowest for the users of the tabular lists of project interdependencies.

Overall, these mixed findings provide some weak support for H4(a), indicating that the level of attention to the task and the level of understanding of the interdependencies are higher for users of visual tools.

Summary and conclusion

The findings support most of the hypotheses and indicate that visual tools, VPM in particular, are correlated with higher decision quality and may have 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, however more research is required to determine whether visual tools can alleviate the time pressure by taking advantage of human cognitive capabilities in processing visual information. The findings indicate that visual tools may contribute to higher levels of engagement with decision-making tasks and result in better decisions. In addition, the research suggests that the use of VPM makes the strongest contribution to the understanding of project interdependencies and the flow-on effects of project decisions across the portfolio, and may contribute to higher decision quality.

The levels of support for the hypotheses are summarized in Table 4.

Table 4: Summary of findings for the hypotheses

H1	**Supported.** The type of tool used to evaluate project interdependencies is correlated with the quality of the resulting PPM decisions.
H1(a)	**Some support.** The use of visual data representations (dependency matrices and VPM displays) are weakly correlated with better quality PPM decisions.
H1(b)	**Strong support.** The use of VPM displays is correlated with better quality PPM decisions than use of the other two tools, at a significance level of 0.05.
H2	**Strong support.** Perception of better time adequacy strongly correlates positively with the quality of the resulting decision, at a significance level of 0.01.
H3	**Not statistically supported.** Relationships are not statistically strong enough to support H3 (that users of visual displays may feel less time pressure during decision making than users of non-graphical tools).
H4	**Supported for four of the five items**. Higher levels of engagement and analysis during decision making are correlated with higher quality decisions, except for the item "the task caused me to think", which showed no correlation.
H4(a)	**Support for two of the five items**. Use of visual displays is correlated with higher levels of attention to the task and levels of understanding of interdependencies.

While many of the findings are as hypothesized, other findings raise questions and suggest a need for further testing. The degree to which the decision task caused the participants to think is the only measure that was not correlated with decision quality or tool type. On the whole, the participants reported that a fairly high level of thinking was required by the task; this may be explained by the fact that the task was designed to be difficult and to required cognitive effort regardless of tool type. The findings on the degree to which the interdependency information was used to influence the decision are counter-intuitive, suggesting further testing for clarification or verification. The findings that tabular lists offered the lowest level of assistance in understanding interdependencies and the impact of decisions on other projects, and that the weak interdependency information was most likely to influence the decisions for users of tabular lists, may illustrate an example of bounded rationality and explain the poor decision quality among that group.

This research complements research conducted in organizational settings that suggests that VPM displays can provide support for strategic decision making and are useful as a communications tool (Killen and Kjaer, 2012). The earlier organizational research also highlights the role of the organizational culture in promoting information sharing and communication to support decision-making processes and tools. The organization-based study provides real-life experience and feedback on the use of VPM; however, due to the complexity of organizational environments such research is not able to establish the significance of 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; the triangulation improves the level of confidence in the findings.

The findings of this research provide implications for management. Increased use of visual displays of project interdependencies, VPM in particular, is indicated as these tools are associated with higher levels of engagement in decision making, better understanding of project interdependencies in complex project portfolios, and higher-quality decisions. In addition, the strong relationship between perceptions of time adequacy and improved decision quality suggests that efforts to reduce time pressure will provide benefits. 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.

This study also has implications for future research. Experimentation is shown to be useful, especially as a complement to organization-based research. The study's limitations include potential bias due to the design of the decision scenario, and further studies with different scenarios should be conducted. There are also limitations inherent in controlled experimentation, for example the results may be biased due to 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 multiple types or strengths of dependencies would affect the findings. Future experiment-based research should consider alternate experiment design options and aim to triangulate findings with organization-based research for improved validity and reliability.

In conclusion, this classroom-based decision experiment highlighted the importance of ensuring adequate time and the benefits of using visual tools to support PPM decision-making. The study supports earlier organization-based research and provides a practical example of experimentation in project and portfolio management research. The findings indicate that visual tools, network mapping tools in particular, have the potential to improve the quality of project portfolio decisions.

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