Understanding project interdependencies: exploring the role of visual representation, culture and process

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Abstract

Project portfolio management is central to many organizations' strategic processes and requires consideration of multiple factors and the ability to envision alternative future consequences to support strategic project portfolio decision making. Complex project portfolios with multiple project interdependencies are characteristic of many project environments, yet existing methods do not provide the clear understanding of project interdependencies that is required.

This exploratory study aims to improve organizational understanding of project interdependencies through two loosely coupled avenues of investigation conducted in tandem in a telecommunications and a defense organization. The first avenue of research introduces a new type of visual representation and shows that the creation of graphical network displays of projects and their interdependencies can provide benefits by supporting communication and strategic portfolio decision making. The second avenue of research tests a conceptual model and highlights the importance of both the culture and processes in an organization's understanding of project interdependencies.

Keywords: Project Portfolio Management, Project Success and Strategy, Project Interdependencies, Complexity, Visual Representations, Social Network Analysis

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1. Introduction

Decisions about project investments are central to the realization of strategy in many organizations, especially the increasing number of organizations that are project based (Maylor et al., 2006; Thiry and Deguire, 2007). Project portfolio management (PPM) aims to enhance the return from project investments and contribute to an organization's competitive advantage by providing a holistic framework for the strategic management of the project portfolio. PPM requires consideration of multiple factors and the ability to envision alternative future consequences to support and enhance strategic project portfolio decision making.

Many PPM tools and methods, while providing a portfolio-level perspective for balancing project decisions, still treat each project as an isolated entity. 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. In portfolios where many projects are interdependent, these interdependencies must be understood for effective decision making (Blau et al., 2004; Verma and Sinha, 2002).

PPM is more than an extension or scaled-up version of project management; the inter-project effects are more complex and difficult to predict (Aritua et al., 2009). Managing a portfolio of projects with uncertainty, dynamism, and complexity represent a complex multi-dimensional challenge. This challenge is amplified by the presence of interdependencies (Collyer and Warren, 2009; Perminova et al., 2008) and the management of interdependences is an area of weakness for PPM (Elonen and Artto, 2003).

The research presented in this paper aims to help improve organizations' ability to understand the interdependencies within a project portfolio, and therefore improve their ability to make strategic portfolio decisions. The research asks whether network mapping visualizations can help organizations understand project interdependencies, and it explores other factors within a project environment that may influence that understanding. The research was conducted in two loosely coupled studies: the application of a

network mapping approach for the visual representation of project interdependencies and the testing of a conceptual model of the factors that influence organizations' understanding of project interdependencies.

Section 2 starts with a review of the literature on the use of visual representations to support managerial and strategic decision making (Section 2.1). In Section 2.2 we present a brief overview of the literature on PPM and strategy, including a discussion on the visual tools commonly used to support project portfolio decision making. Section 2.3 explores the nature of project interdependencies and proposes a conceptual model on the factors that affect an organization's ability to understand project interdependencies. Finally, to conclude the literature review, Section 2.4 provides a brief review of literature on the application of network mapping and analysis for strategic and managerial decision making.

Building on the findings of the literature review, Section 3 introduces a network mapping approach to visualize project interdependencies that is proposed to support strategic project portfolio decision making. The methods employed for the two avenues of investigation in this exploratory study are then outlined in Section 4, followed by the findings and discussions from the two approaches in Section 5. Finally, we present conclusions, acknowledge the limitations of the research and suggest avenues for future research in Section 6.

2. Literature review

2.1 Visual Representations and Strategic Decision Making

Visual representations can provide an effective format for displaying and communicating information to support strategic decision making. Graphical forms of communication have the ability to illustrate complex multi-dimensional aspects of organizations in a simple and powerful manner (Meyer, 1991). Human cognitive capabilities process visual information differently from alphabetic, numeric, or verbal information. Visual information enhances analysis because it has the ability to be cognitively processed while preserving spatial orientations and interrelationships between multiple components, whereas

alphabetic, numeric, and verbal information does not have that ability. As summarized by Ware (2005, p.29), the "power of a visualization comes from the fact that it is possible to have a far more complex concept structure represented externally in a visual display than can be held in visual and verbal working memories". In this way, visualization compensates for limitations in working memories and extends both the capacity and the duration of stored information (Tergan and Keller, 2005). For example, in a recent study, visual displays are shown to aid in the attention, agreement, and retention of strategic information (Kernbach and Eppler, 2010).

Visual representations support a two-way relationship with strategy by helping to communicate and to shape strategic thinking (Warglien and Jacobides, 2010). Careful selection of the data and interrelationships presented in spatial and visual displays can guide decision makers. When used for strategic processes, visual representations must be able to assess multiple factors, capture historical events, and illustrate complex relationships (Platts and Tan, 2004). Common displays, such as 2 x 2 Matrix displays, are able to present multiple types of information in "2½-Dimensional" formats that are very powerful if well designed (Warglien, 2010). Most strategy displays are static by nature and, although there are attempts in some displays to incorporate representations of change and dynamism, the potential for *static bias* in visual displays should be acknowledged and studied (Warglien and Jacobides, 2010).

The advent of computers and software-based tools has greatly enhanced the ease of creating visual representations, making new types of visualization practical by providing new ways of collecting and displaying data (Dansereau and Simpson, 2009). Computer-based tools with visual interfaces combined 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). For example, in a study on decision making in resource-constrained projects, computerized algorithms are combined with visual representations to provide the results in a condensed, manager-friendly format that increases acceptance and usability (Rivera and Duran, 2004). Similarly, the *tool for action plan selection* is a software-based tool that visually displays the cause-and-effect relationships between projects using a *connectance* concept

between options in order to assist managers in evaluating the consequences of strategic decisions (Platts and Tan, 2004).

We have summarized here a few studies that explore the use of visual representations of strategic decision problems; however, there is a need for more research to better understand how they are used in practice and what types of visual representations improve strategic decision making (Warglien and Jacobides, 2010). Bresciani and Eppler's (2010) study of 12 common types of visual knowledge displays indicated the relative strengths of these methods. Some types of displays were found to be more flexible and adaptable, while others were suited to specific purposes. The authors found that 2x2 Matrix displays, like those used in portfolio maps, supported decision making and had particular strengths in evaluating and sharing information. In order to communicate effectively, the type of visual representation must be carefully selected and tailored to deliver the intended message in a way that is appropriate for the audience (Platts and Tan, 2004). These are important considerations for developing a method for communicating information about project interdependencies to support strategic project portfolio decision making.

2.2. Project portfolio management and strategy

PPM is a central part of the strategic management process as it involves decisions about which activities an organization should pursue to best realize strategic goals. As organizations increasingly turn to project forms of organization, projects are often the main vehicle for delivering organizational strategy (Artto et al., 2004; Dietrich and Lehtonen, 2005; Meskendahl, 2010; Poskela et al., 2003; Turner, 1999). The 'projectization' of organizations has many drivers, including competitive pressures, increased complexity of organizational activities, and the increasing availability and success of project management (PM) tools (Cleland, 1999; Webb, 1994). The past two decades have seen strong growth in the capability and skills of the PM community and in the prevalence of PM methods in organizational activity (Maylor et al., 2006). In recent years, PPM has gained attention as a way of aligning projects with strategy and ensuring

adequate resourcing for projects, prompting organizations in a variety of industries to extend their PPM capabilities (Crawford, 2006; Maylor et al., 2006).

PPM processes help organizations manage their project portfolios through a range of tools and methods designed to generate and evaluate project information and to steer decision making to maintain a balanced project portfolio that is aligned with strategic goals (Cooper et al., 2001; Levine, 2005). The literature suggests that the successful management of project portfolios extends beyond the processes used, and that the organizational structure, people, and culture are also important aspects of an organization's overall capability to manage its project portfolio (Killen and Hunt, 2010). Research repeatedly shows that PPM must be developed over time (Cooper et al., 2001; Martinsuo and Lehtonen, 2007) and that, although a range of methods and tools are commonly used for PPM, they must be tailored to the individual environment for best results (Loch, 2000). The proliferation of 'best practice' studies and maturity models highlights the relationship believed to exist between PPM maturity and improved outcomes (Kahn et al., 2006; O'Connor, 2004; Pennypacker, 2005; PMI, 2003). Similarly, the strong focus on processes and methods for PPM reflects a belief that these processes and methods can improve PPM outcomes (Archer and Ghasemzadeh, 1999; Phaal et al., 2006; PMI, 2006); indeed, empirical research provides evidence of some practices that are associated with improved outcomes (Cooper et al., 2001; De Reyck et al., 2005; Jeffery and Leliveld, 2004; Killen et al., 2008).

While the relationship between strategy and projects is sometimes represented as a one-way 'downward' process from strategy to projects (Bridges, 1999; Dinsmore, 2006; Meskendahl, 2010; Nelson et al., 1999; Turner, 1999), several studies indicate a two-way interaction between operative (PM) and strategic levels of the organization. PPM processes draw from and inform strategy and mediate the integration of strategic-level and operative-level activities (Poskela et al., 2005). PPM activities are shown to facilitate the effective combination of top-down strategic intent with bottom-up emergent strategy evolution in several other studies (Burgelman, 1991; Milosevic and Srivannaboon, 2006; Noda and Bower, 1996).

These studies show that PPM is an important strategic capability with a role in delivering and in shaping strategy. This strategic role helps to explain the strong degree of managerial and academic interest in understanding and improving PPM decision-making capabilities. Many PPM tools and methods focus on the strategic aspects of PPM decisions, and many of these are graphical or visual tools.

Research indicates that 'best practice' organizations make PPM decisions in meetings, and use graphical and visual information displays such as portfolio maps and roadmaps to facilitate group decision making (Christensen, 1997; De Maio et al., 1994; Killen et al., 2008; Mikkola, 2001; Rungi, 2007). Portfolio maps display projects and the strategic options they represent on two axes, augmented with additional data to provide a visual representation that incorporates information such as strategic alignment, risk, return, and competitive advantage (Cooper et al., 2001; Mikkola, 2001; Phaal et al., 2006). Roadmapping tools use visual representations of the timing of sequenced and linked development stages for planning and communication and for assisting with the integration of business and technology strategy (Albright and Nelson, 2004; Groenveld, 1997; Phaal et al., 2001). Due to the multiple types of data represented, these types of visual displays are often called two-and-a-half dimensional (2½-D) displays (Warglien, 2010).

2.3. Project interdependencies

Much of the literature and research on PPM treats each project as an independent entity, however increasingly the importance of acknowledging and understanding project interdependencies is highlighted (Collyer and Warren, 2009; Dahlgren and Söderlund, 2010; Elonen and Artto, 2003; Rungi, 2010; Söderlund, 2004; Stummer and Heidenberger, 2003). Projects are said to be interdependent when the success of a project depends upon other project(s). For example, projects may experience resource interdependencies (the need to share resources or wait until scarce resources are released by another project), market or benefit interdependencies (complementary or competitive effects), outcome dependencies (the need to use the end result of another project—these can be technical or other outcomes),

learning dependencies (the need to incorporate the capabilities and knowledge gained through another project), and financial dependencies (Blau et al., 2004; Eilat et al., 2006; Verma and Sinha, 2002).

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 (Blau et al., 2004; Rungi, 2007, 2010; Verma and Sinha, 2002). PPM processes and tools are employed 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), and researchers are active in developing and evaluating new decision making tools to manage the challenge of PPM (Aritua et al., 2009). Visual displays are among a range of tools commonly used to enhance strategic project portfolio decision making; however, the management of complex and highly interdependent project portfolios creates additional challenges that are not adequately addressed by current PPM tools and techniques. The literature on PM, learning, and knowledge sharing indicates that several aspects of the project culture may also affect an organization's ability to understand and manage project interdependencies. A combination of the right processes and the right culture enables organizations to learn from past experiences and avoid reinventing the wheel (Williams, 2007).

2.3.1. Understanding Project Interdependencies: Culture and the Project Environment

Although most PPM literature focuses on processes and methods, an emerging body of research highlights the importance of organizational and team culture, in particular the culture of the project environment. Research repeatedly reveals 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; Killen et al., 2008; Kim and David, 2007). Management support is proposed to influence PPM outcomes through encouragement for collaboration and information sharing (Jonas, 2010). The complexity of the modern project environment strengthens the need for project managers to be able to adapt to the environment while maintaining a balancing level of control and accountability. This can be

achieved by a high level of trust between portfolio managers and project managers and the creation of a culture that encourages information sharing among project teams (Aritua et al., 2009).

In order to manage interdependencies between projects and to avoid repeating the same mistakes, a learning cycle must exist that enables lessons learned to be captured and transferred to other current or future projects (Davies and Brady, 2000; Kerzner, 2004). There are, however, barriers to such transfer and learning, including the temporary nature of project structures and the tendency of knowledge to remain trapped in knowledge silos and not shared effectively across the organization (Brady et al., 2002; Lindkvist et al., 1998). To remain constantly aware of how their projects fit in the evolving strategy, project and portfolio managers must actively communicate and share information (Aritua et al., 2009). For full information transparency and sharing of information, the project environment must promote a culture of trust and openness within and between project teams, project managers, and portfolio managers (Kim and David, 2007).

2.3.2. Understanding Project Interdependencies: Processes and Methods

Organizations manage dependencies between projects using a variety of processes and methods. Management strategies to improve between-project communication are recommended in the literature (Nobeoka and Cusumano, 1995; Platje et al., 1994). Post-project or post-implementation reviews are often recommended for capturing and transferring project knowledge; however, research indicates that such reviews are not regularly completed and that the transfer of the knowledge presents an ongoing challenge (Killen and Hunt, 2010; Williams, 2007). Methods for capturing both tacit and explicit knowledge and for transferring that knowledge must be highly customized to the particular project environment (Williams, 2007). To support project portfolio decision making, organizations need to be able to capture, codify, and share data from previous or concurrent projects (Kim and David, 2007) and to view that data from a portfolio perspective (Cooper et al., 2001; Durant-Law, 2012; Levine, 2005; Mikkola, 2001).

Resource dependencies are often addressed by scheduling optimization systems; however, these types of systems require large amounts of numerical input and are not considered useful in many PPM environments (Coldrick et al., 2005; Rungi, 2009, 2010). Visual representations are considered more useful and researchers are active in developing and evaluating such methods. A visual method for viewing dependencies through overlapping project graphics has been proposed, although there is no evidence of application of this method in practice (Rungi, 2007). Dependency matrices are a more common method that provide a visual means of understanding interdependence between projects (Dickinson et al., 2001; Slade 2009). The dependency matrix is similar to the design structure matrix (DSM) that is applied in development environments to manage interdependent tasks (Browning, 1998; Makumbe, 2002; Yassine, 2004). In a DSM, the rows capture the information inflows, whilst the columns capture the information outflows between components or sub-projects in a given system (Batallas and Yassine, 2004), whereas a dependency matrix captures inward and outward between-project dependencies. The domain mapping matrix (DMM) has been proposed as another approach to multi-project management that works with and augments DSM methods that capture task and activity interdependency within a project (Danilovic and Browning, 2007; Danilovic and Sandkull, 2005). A DMM relates two DSMs to each other and enables project interdependencies to be identified and tracked across project domains, providing a basis for communication and learning across domains and supporting decision making (Danilovic and Browning, 2007). DMM and DSM methods provide detail of task interdependency and some cross-project visibility and support for management decisions in complex product development environments.

Dependency matrices offer a higher-level approach that is implemented in many types of project portfolio environments to support strategic decision making; however there are weaknesses to such matrix-based tools. In a recent study existing matrix-based approaches were found unsuitable for the management of the complexity and interdependency of research and development projects (Laslo, 2010). Dependency matrices use a two-dimensional grid to display and analyze bi-directional dependencies between each pair of projects in a portfolio. The rows and columns are each labeled with the set of projects in the portfolio,

as illustrated in Figure 1. The dependency matrix can be used to capture a range of dependencies; however, this analysis does not reveal accumulated or multi-level interdependencies. For example, the dependency matrix in Figure 1 shows that project F is dependent upon project C, and on a different line shows that project C is dependent upon project A. The resulting multi-level dependency between project F and project A is not clearly indicated on the dependency matrix in Figure 1. Understanding these multi-level relationships is important to fully understand project interdependence in a portfolio. This paper proposes that network mapping and analysis tools have the potential to enhance the understanding of multi-level project interdependencies.

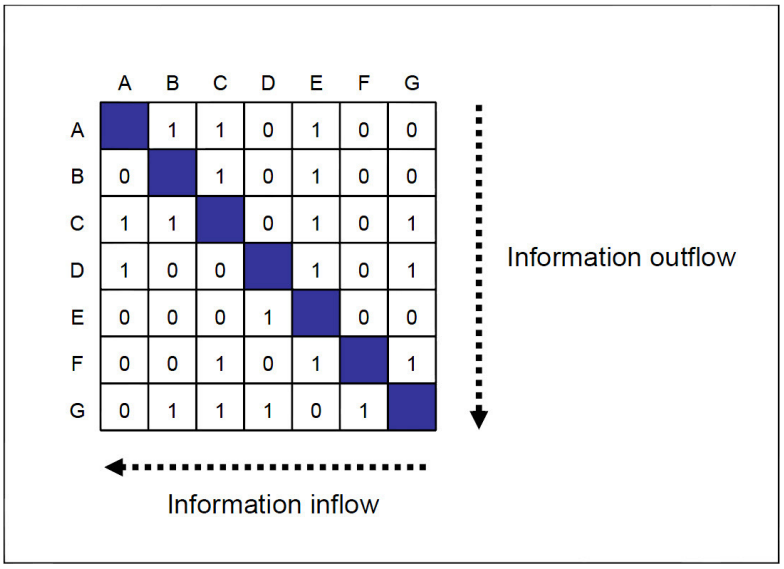

Figure 1. Dependency Matrix illustrating inward and outward dependencies between projects A-G (Batallas and Yassine, 2004, p.2)

2.3.3. *Understanding Project Interdependencies: Conceptual Model*

The literature identifies multiple aspects of the culture and the processes that are important for organizational understanding of project interdependencies. These culture and process factors are proposed to work together to improve the understanding and management of interdependencies between projects. Figure 2 presents a conceptual model based on the literature on PPM and the management of project

interdependencies. Relationship R1 proposes that a project environment with a culture that supports between-project communication and learning is positively correlated with improved understanding of project interdependencies (UPI). Relationship R2 proposes that the establishment and use of processes for between-project communication and learning is positively correlated with improved UPI. Relationship R3 identifies the belief that an improved UPI leads to improved PPM performance. The multiple items used to test this conceptual model are detailed in the Method section below.

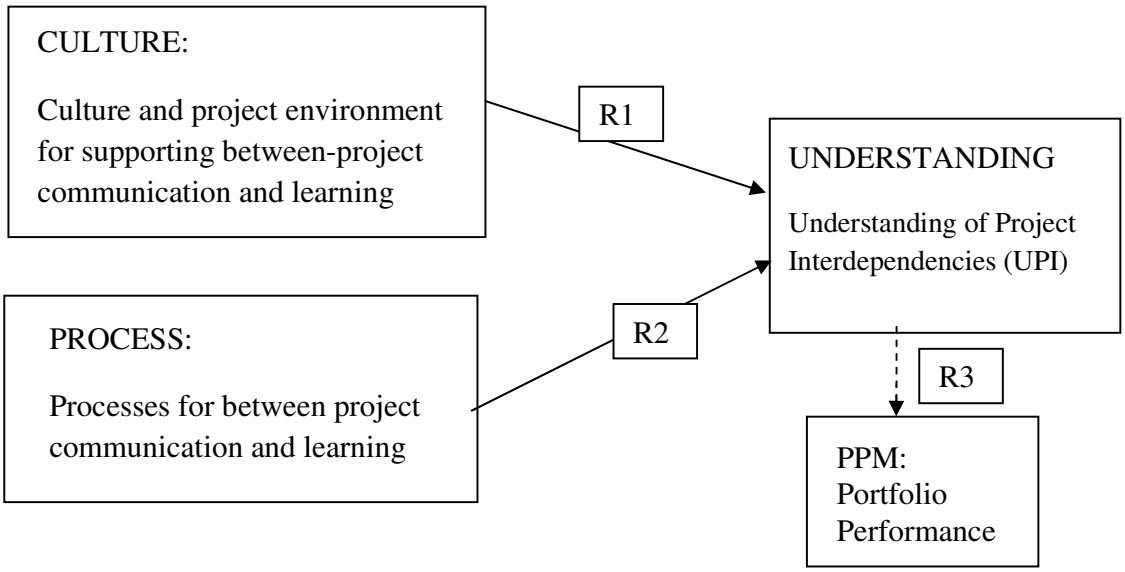

Figure 2. Conceptual model of factors influencing the understanding of project interdependencies (UPI)

2.4 Network Mapping and Analysis

Network mapping tools have the ability to display relationships between nodes in a network at multiple levels and to reveal accumulated effects (Scott, 2008). The mapping uses software-based tools that help to record, analyze, and visually display the relationships between items or *nodes* in a network. Such maps facilitate enhanced analyses through modeling of proposed or actual changes in the network. The graphical displays provide 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).

Social network analysis (SNA) and the related organizational network analysis methods are common applications of network mapping where relationships between people or organizations are analyzed and presented in a visual form (Anklam et al., 2005). The network mapping exercise involves collecting data from people representing each node of the network on their interaction and relationships with other nodes. For SNA the nodes are individual people who answer questions about their interactions with other people. SNA is shown to be an aid to understanding and improving relationships between networks of people or organizations, promoting collaboration, supporting critical nodes in the network, and managing and maintaining networks during organizational restructuring (Cross et al., 2002; Scott, 2008; Wasserman and Faust, 1994).

Applying SNA to a PM environment, Hossain (2009) found that network centrality, an individual's position in the social network, correlated with their influence on project coordination, whereas their position in the organization did not. Also in the PM domain, network mapping of the interdependencies between selection criteria enabled better evaluation of alternative project contractors (Darvish et al., 2009).

Network mapping has many other existing applications, including mathematical, biological, and economic modeling (Hanneman and Riddle, 2005). Network mapping has also been used in conjunction with design structure matrix tools to manage interdependencies between tasks in product development environments (Batallas and Yassine, 2004; Bradley and Yassine, 2006; Collins et al., 2009). Bradley and Yassine (2006) measured product development team interactions and information flows, and demonstrated the use of network mapping and analysis in identifying the most important nodes in the network.

The validity of network mapping analyses depends upon the accuracy and completeness of the data. Each application must consider the best way of obtaining representative data for the analysis. In one study, data mining techniques were used to evaluate email records to avoid the potential bias introduced by manual data collection through interviews or surveys (Hossain and Wu, 2009); however, no data collection

method is fully free from bias, and email records may introduce a different type of bias. Most SNA analyses collect data from individuals and software tools are available to assist with the data collection and to reduce the bias that could be introduced in face-to-face settings.

3. Visualizing interdependencies as a network map

The literature review highlights PPM as a strategic activity. We synthesize the research on PPM and project interdependencies with the findings on the use of visual representations for strategic decision making and the findings on the applications and benefits of network mapping, and propose that a network mapping approach may support strategic project portfolio decision making by providing a visual representation of the interdependencies between projects. Research findings illustrate the benefits of visual displays for strategic decision making; however, network mapping is not considered in the existing literature. For example, network mapping or similar approaches were not included in Bresciani and Eppler's (2010) study of 12 commonly used types of visual knowledge displays. Platts and Tan's (2004) *tool for action plan selection* is the closest example in the literature to a network mapping method for strategic decision making. However, although it employs a *connectance* concept between options, it lacks flexibility in the types and directions of connections and is suited more for specific operational environments rather than strategic decision making.

Visual project mapping (VPM) is the name we have given to the technique developed for this research to create network maps of the projects and the interdependencies between projects within a portfolio. Initial tests employing a similar approach indicate that network mapping and analysis can be useful for project, program, and portfolio management (Durant-Law, 2012). VPM considers each project as a node in the network and captures and displays information on the relationships or interdependencies between nodes using arrows, as shown in Figure 3. There are many options for VPM displays; for example, in Figure 3 the circles representing each project (node) are sized according to the level of accumulated dependencies; a larger circle indicates that the project may be more important due to the fact that multiple projects

depend upon it. Alternatively, the size and color of the circle can be related to project characteristics such as the size of the investment or the area of responsibility. In addition, the strength or type of interdependency can be indicated through the use of arrows of a different line weight or of different color and textual tags or labels can be added. Once data have been entered into the NetDraw software tool (Borgatti, 2002), VPM displays can be created and re-created, by dynamically filtering variables and rearranging the data to highlight different types of data and relationships. By allowing a subset of data to be displayed, filters provide the ability to highlight critical connections or selected information. We propose that this type of visual display of project interdependencies may support strategic decision making and contribute to PPM. Section 4 outlines the methods we used to explore the use of VPM in organizational settings.

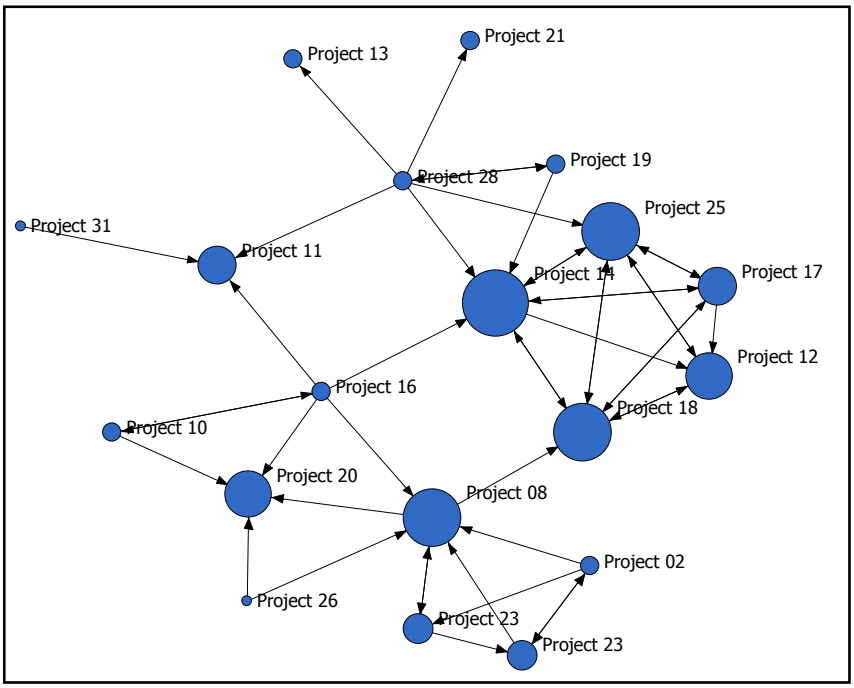

Figure 3. Example visual project map (VPM)

4. Method

Our exploratory study investigated the management of project interdependencies in complex project portfolio environments, defined for this research as environments with multiple relationships or dependencies between at least 80 per cent of the projects. Two separate avenues of investigation were followed: (1) evaluation of the use of visual project mapping (VPM) displays for understanding project interdependencies to support strategic decision making in an organizational setting, and (2) investigation of the relationships between the project culture and environment, the processes, and the understanding of project interdependencies, as shown in the conceptual model in Figure 2.

We selected two organizations, one in the public sector (defense) and one in the private sector (telecommunications), and identified a highly interdependent project portfolio to use as the basis for the study in each organization. The two avenues of research were investigated in tandem in the two organizations through a three-phase mixed-method study. The three phases of the research were:

(1) initial qualitative research and scope definition

(2) quantitative data collection and analysis

(3) final qualitative feedback session.

The first phase of the research comprised semi-structured interviews, phone conversations, and analysis of project and portfolio documents and information to qualitatively evaluate the organizational environment and the nature of the interdependencies. This first phase formed a base for the research, particularly the first avenue of research, the testing of VPM, by informing the tailoring of the data collection methods and determining the bounds of the portfolio for the study. Both authors and a research assistant were present at the interviews to reduce bias and to enhance the ability to collect, interpret, and analyze the qualitative data. The initial interviews lasted for 1.5 hours with two representatives from Org1 (telecommunications) and 1.75 hours with two representatives from Org2 (defense).

In the second phase we collected and analyzed quantitative data for both avenues of the research. We collected data on project interdependencies to build VPM displays for the first avenue of research, and Likert scale data on the organizational culture and processes to test the conceptual model on factors influencing the understanding of project interdependencies for the second avenue of research. Both types of data were collected from project managers using an online data collection tool. We customized the data collection instrument, based on input from the first phase, to reflect the specific projects in the relevant portfolio and the terminology used by that organization. The project managers responsible for each project in the selected portfolio were asked to input the data using the ONA Surveys survey tool[1]. The ONA Surveys tool was originally designed for the analysis of organizational networks and was customized for this research to collect data on project relationships (interdependencies) and to include a range of additional items on the project culture and processes. The survey tool allowed each project manager to select projects from a list, or to nominate other projects on which they depend to deliver their project, or that they believe depend upon their project. The respondents then categorized each dependency with respect to the strength and type of dependency. Strengths of minor, important, and critical were defined as follows (similar statements were offered for the other direction of dependency):

> *Minor* = While my project is dependent on this project, my project is able to be completed without major adjustments if the other project is delayed, cancelled, or significantly altered.
>
> *Important* = My project will experience detrimental effects (delay, reduction in scope or quality) if this project is delayed, cancelled, or significantly altered.
>
> *Critical* = My project will not be able to be completed or will experience very significant detrimental effects if this project is delayed, cancelled, or significantly altered.

Respondents were also asked to nominate which among four types of dependencies is the strongest. The types of dependencies were:

[1] ONA Surveys is a tool for capturing network data for display in network maps—www.ONAsurveys.com.

Outcome = Dependent upon the outcome or deliverable of another project

Learning = Dependent upon learning or skills development in another project

Resource = Dependent on release of resources (human or other) from another project

Other = Dependent on some other aspect of another project

We derived the item questions and variables used to test the conceptual model from factors identified in the literature (Aritua et al., 2009; Kim and David, 2007; Williams, 2007). Questions on formal and informal processes for capturing learning, accessing data, and transferring learning drew upon a survey on project learning (Williams, 2007). The three questions designed to measure the level of understanding of project interdependencies were developed specifically for this survey, as no existing survey or study was found that investigated the ability of individuals or organizations to understand project interdependencies. We kept the number of questions to a minimum to improve the response rate. The items were selected to focus on the culture and process factors that relate to a portfolio management perspective; these are summarized in Table 1. We captured the responses using a Likert scale with labeled rating descriptions to improve the validity and reliability of responses, as shown in Table 2.

At the completion of the second phase, we mapped project interdependencies by VPM using network mapping and analysis tools (Borgatti, 2002), and we tested the relationships on the conceptual model using SPSS statistical analysis of the project culture and process variables. We used descriptive statistics to summarize the responses, with factor analysis identifying the groupings of items that *go together* (Ticehurst and Veal, 1999) and confirming the items that best supported the constructs in the conceptual model. We used two-tailed Pearson correlations to test the relationships on the conceptual model.

Table 1. Project culture and process variables and descriptions.

Variable Name	Description
UPIproj	I feel that I have a good understanding of the project interdependencies across the project portfolio
UPdepend	I am aware of all of the projects that my project depends upon or that will impact the success of my project
UPtheydepend	I am aware of all of the projects that depend upon my project - the projects that will be affected by the success of my project and will be impacted by changes in my project
Continuity	We have strong continuity among our project managers
Accessdata	We are able to access relevant data from previous or concurrent projects
LearnMistakes	Our project processes help us learn from past mistakes and to avoid making the same mistakes again
Trust	There is a high level of trust between project managers
TrustPort	There is a high level of trust between project managers and portfolio managers
DiscussWeak	Project managers openly discuss their projects' weaknesses and failures in order to share lessons learned and to improve future projects
ProcessProjPerf1	We have formal processes for monitoring project performance
Transfer	We consistently use formal processes to ensure that learning and information from projects is transferred to dependent projects
CaptureReview	We capture learning from projects through end-of-project reviews
CaptureMilestone	We capture learning from projects through reporting on project milestones
InformalTransfer	Informal mechanisms are regularly used to transfer learning and information to dependent projects

Table 2. Example of the Likert scale descriptions used in the survey.

Variable : UPIproj	**I feel that I have a good understanding of the project interdependencies across the project portfolio**
5	Yes, I believe I am aware of nearly all the interdependencies across the project portfolio
4	I am aware of most of the project interdependencies across the project portfolio
3	I am aware of some of the project interdependencies across the project portfolio
2	I am aware of a few of the project interdependencies across the project portfolio
1	No, I am not aware of the interdependencies in the project portfolio other than those that affect my project

In the third and final phase of the study we collected rich qualitative data during a semi-structured two-hour feedback session with each organization, with a second feedback session (45 minutes) conducted at Org2 to allow an additional high-ranking executive to review the results. At each organization, we presented the project maps and descriptive statistics from the survey items to three senior and executive-level portfolio stakeholders. First we presented the prepared maps, followed by an interactive 'live' map generation session where executives could nominate scenarios and displays to view. This allowed us to generate what-if scenarios and specifically-filtered displays based on the executives' interests. During these sessions we collected feedback through careful recording of the high-level portfolio stakeholders' unstructured reactions, responses, questions, and discussions as they were reviewing the descriptive statistics and viewing the maps. We then generated further responses using a semi-structured question format. Finally, we analyzed the data to evaluate whether and how the high-level portfolio stakeholders felt that VPM influenced their understanding of project interdependencies.

This exploratory research generated both qualitative and quantitative data. Data were collected from a total of 58 respondents; 34 respondents from Org 1 and 24 respondents from Org 2 (return rate of 83 per cent). The data on specific project interdependencies confirmed that more than 80 per cent of the projects

in the two organizations' portfolios had at least two interdependencies with other projects in the portfolio, thus confirming the suitability of these portfolios for the research. We used these project interdependency data to create VPM displays using NetDraw (Borgatti, 2002). We then created several VPM 'snapshot' displays using a variety of filtering options and display options in preparation for the feedback sessions. The qualitative data generated during the feedback sessions captured the senior portfolio stakeholders' responses to the 'snapshot' displays, as well as to the interactive session where VPM displays were dynamically filtered and adjusted. These findings, which informed the first avenue of research, are reported in Section 5.1. We then analyzed the quantitative data on the project culture and process variables for correlations with respect to the conceptual model in Figure 2, as reported in Section 5.2, in the findings and discussion for the second avenue of research.

5. Findings and Discussion

The findings from each avenue of investigation are presented separately below, followed by a discussion for each section.

5.1. Findings and Discussion: Research Avenue 1 - Visual Project Mapping

We used the qualitative data from the feedback sessions to collect information on four main topics: the ease of interpretation of the maps, the participants' ability to gain insights from the maps, the participants' views of the benefits they may be able to gain from VPM, and their ideas on potential implementation and use of VPM in an organization. The questions were stated at the beginning of the session as part of a review of the aims of the research and the structure of the feedback session. Much of the spontaneous feedback from participants addressed these questions and further feedback was obtained by posing the questions again in a semi-structured interview format toward the end of the feedback sessions. Feedback on the four main topics is presented in Sections 5.1.1–5.1.4.

5.1.1. Ease of interpretation of the maps

The VPM displays use circles for each project and arrows to indicate which project depends upon another project, as shown in Figure 3. Some managers found the meaning of the direction of the arrow not initially intuitive. The logic we used followed conventions of SNA, where the arrow points to the node that is depended upon, which is contrary to the traditional flow charting conventions where the arrow points the other way. As arrowheads make a larger visual impact, we adopted the SNA approach because it makes it easier to identify projects that have many dependents. After we explained the conventions, the managers understood the logic and felt that they were able to interpret the maps accurately.

Upon viewing the maps, the portfolio manager [p1] at the first organization [Org1] could see "flow patterns from the data that were easy to interpret" [Org1p1]. A high-ranking decision maker at Org2 exclaimed that the maps provided the ability to "see the connections and where the work needs to be done … it is like moving from a 2D to a 3D picture!" and commented further, "it does add value to me and I can see (the relationships) which I had not seen before. You can see the connections, that is excellent" [Org2p1].

VPM displays were presented using different levels of filtering and a range of other options such as the use of color, the size of project circles, and the addition of notations. While the advantages of the different display options were appreciated by the participants, each acknowledged that the best type of display would depend on each individual situation. Managers at Org1 suggested that if organizations were using VPM regularly it would be best to adopt a few standard formats so that the maps could be quickly and easily interpreted.

5.1.2. Insights from the maps

Both organizations found new insights by viewing their project interdependencies in the VPM format. The clusters of interdependence revealed by the maps provided some very powerful insights, insights that were not apparent using other methods. The new insights clarified the relative importance of the projects based on dependency clusters and chains and prompted action on an ongoing project issue in Org2. Some of the

insights resulted from the maps presenting information in a new way, making connections easier to grasp ("there is a forest of information within project portfolios and the network maps allow you to see the 'bang for buck'" [Org1p1]), and other insights stemmed from the data being collected from the project managers and providing information not previously available ("We have new information available here, that hasn't existed before to help us make decisions and justify actions" [Org2p2]). Another manager commented, "I'll tell you … this brings dependencies out to the light, and gives me a better appreciation (of the dependencies)" [Org1p3] and "the maps allow bottlenecks to be predicted within projects and external to projects … and allow for the prioritization of projects to show the risks in following through with a decision" [Org1p3].

Participants also identified more general insights, with the maps providing a useful antidote to the tunnel vision that can be caused by the increasing specialization in the workforce. In the increasingly technical and complex project environment, specialization is necessary, but it can limit strategic vision. Participants felt the maps helped to "contextualize the information" and provide a vision across the specializations [Org2p1].

5.1.3. Benefits to organizations

Both organizations cited potential benefits related to communication and decision making, although the managers had different views of the relative benefits. For example, one manager at Org1 saw the value of the maps primarily at the decision-making level because "they add rigor and transparency" [Org1p1], but another manager felt that the maps would be more useful for communicating the decisions than making the decisions [Org1p2]. At both organizations, participants felt the maps were very useful for communicating the portfolio interdependencies, both upward to support strategic decision making and downward to help individual project managers understand priorities from a portfolio perspective. The maps were "definitely a very good communications tool, really good" [Org1p3] and very powerful for getting senior manager support with the "direct evidence" the maps provided [Org2p2]. The value of such

maps was particularly strongly emphasized at Org2, where a senior decision maker commented that with the visual representation of the data one could "go straight in" and make decisions or take action - "you are on a winner here" [Org2p1].

5.1.4. Implementation of VPM

Managers reported that the implementation and use of VPM on an ongoing basis in an organization presented some potential challenges. Ensuring that the benefits outweighed the effort would require deeper investigation [Org2p2]. As this research was the first time the approach was trialed in an organizational setting, the creation of VPM displays required more time than would probably be required if implemented on an ongoing basis; however, it was not within the scope of the research to try to predict the ongoing level of effort that would be required. Another challenge cited by the participants was related to the dynamic nature of project portfolios. The method of data collection used for the research has generated a snapshot of the project portfolio at a given point in time; however, managers at both organizations agreed that developing a method to regularly refresh the data to reflect the dynamic portfolio would be even more useful. Planning the appropriate frequency for refreshing the data was cited as a particular challenge, as the effort required to keep the data up-to-date needed to be balanced with the benefits gained [Org2p2]. Managers at both organizations considered whether it might be practical to identify and capture the incremental changes as they occur, rather than performing a complete survey of the relationships periodically. A manager at Org1 said they already had methods in place that could probably be adapted to automatically refresh the VPM data [Org1p2]. In addition to incremental updates of the maps, some managers felt that displaying a future scenario using the maps might be useful, while one manager questioned, "How would the maps be affected if a project was completed? How could this be shown in order to then see future interdependencies?" [Org1p1].

5.1.5. Discussion: Research Avenue 1 - Visual Project Mapping:

The two organizations' experiences provide initial insights into how visual representations can be constructed using a network mapping approach, and how such representations can be interpreted and used in practice. The qualitative findings from the feedback sessions indicated that the VPM displays helped illuminate the relationships between projects and provided new insights to the high-level portfolio stakeholders at the two organizations. By highlighting the most important projects in terms of their accumulated interdependencies, and by revealing clusters of interdependence, the VPM analysis provided valuable information about the relative influence and importance of projects that would not be readily apparent through traditional methods of analyzing project interdependencies. Managers at both organizations thought that benefits from using the maps would be derived primarily from their use as decision-making and communication tools. Although both organizations were quite positive about the maps overall, Managers at Org2 were particularly enthusiastic and specific about the benefits, especially as a tool for informing strategic management decisions.

The findings align with and extend existing research. For example, the comments by managers at Org1 – regarding the need to adopt a few standard VPM formats so that the maps could be quickly and easily interpreted – follow common PPM approaches where templates and standard formats for graphs and portfolio maps are developed and adopted to assist with analysis and comparison (Cooper et al., 2001; Loch, 2000). In another example, the comment by Org2p1 that viewing a VPM display was like going from "2D to 3D" aligns with literature that suggests that a well-designed visual information representation in 2D can, in effect, be more than a 2D representation (2½-D is suggested in the literature) due to its power to provide rich and complex information (Warglien, 2010). The combination of computer-generated visual data displays and the human cognitive ability to analyze and find patterns using visual representations has been suggested as one of the most powerful and flexible cognitive systems (Tergan and Keller, 2005). This research provides an example of this combination and presents findings that show how human cognitive capabilities can be supported and enhanced by such displays.

Questions remain unanswered about how organizations can implement VPM on an ongoing basis. Our findings emphasize the need for decisions about the source from which to collect interdependency data, the method for data collection, and the appropriate frequency of data collection and updating. These findings reinforce the literature that emphasizes the need for more research into how visual data displays are used in practice and what types of visual representations will best improve strategic decision making (Warglien and Jacobides, 2010). The danger of *static bias* (Warglien and Jacobides, 2010) was acknowledged in the feedback, as participants explored ways to overcome the limitations of a single map in representing a dynamic portfolio. The findings also align with literature on other visual representations used for PPM and strategic decision making (Loch, 2000; Platts and Tan, 2004), and indicate that organizations need to carefully consider the display options and the specific benefits desired and then design a tailored approach.

5.2. Findings and Discussion: Research Avenue 2 - Factors affecting UPI

This section summarizes and discusses the quantitative findings on the factors influencing the understanding of project interdependencies (UPI).

5.2.1 Data analysis

We analyzed the data to investigate relationships R1 and R2 in the conceptual model in Figure 2. The relationship R3, between UPI and PPM performance, could not be tested in this initial study with only two organizations.

The project culture and process variables clustered into the three constructs identified in Table 3: UPI4, a construct containing four items related to the level of UPI; CUL5, a construct containing five items relating to the culture, such as levels of trust and openness to support the sharing of information in the project environment; and PROC5, a construct containing five items relating to the processes used to capture and share project information. Interestingly, the variable for Continuity was included in the UPI4

construct, whereas it may have been expected to align with the CUL5 construct. This indicates that continuity among project managers may be particularly closely aligned with their level of understanding of project interdependencies.

Table 4 identifies the correlations between the identified constructs and highlights the relationships R1 and R2 from the conceptual model in Figure 2. While both are significant correlations, R1 is stronger than R2, indicating that for this study the culture (CUL5) has a stronger correlation with the level of UPI (UPI4) than the processes and procedures used (PROC5). The relationship between CUL5 and PROC5 is also shown on Table 4; however, it is not a strong or highly significant relationship and is not considered further in this study.

Table 3. Constructs, factor analysis, and descriptive statistics.
Rotated component matrix, small coefficient values (<0.35) suppressed.

Variable Name	**Construct name and components** (in bold)			**Descriptive statistics**	
	UPI4 Cronbach alpha 0.743	**CUL5** Cronbach alpha 0.840	**PROC5** Cronbach alpha 0.887	Mean	Std dev.
UPIproj	**.711**			3.90	0.912
UPdepend	**.764**			4.00	0.879
UPtheydepend	**.709**			3.71	1.043
Continuity	**.510**			2.98	0.934
Accessdata		**.786**		3.30	0.607
LearnMistakes		**.604**	.483	3.26	0.788
Trust		**.762**		3.65	0.758
TrustPort	.472	**.584**		3.58	1.011
DiscussWeak		**.806**		3.24	0.916
ProcessProjPerf1			**.848**	3.87	0.870
Transfer			**.835**	3.46	0.999
CaptureReview			**.722**	3.55	1.066
CaptureMilestone			**.838**	3.55	1.119
InformalTransfer			**.788**	3.69	0.905

Table 4. Constructs and correlations.

Construct	Mean	Std dev	1. UPI4	2. CUL5	3. PROC5
1. UPI4	**3.63**	**0.925**	-		
2. CUL5	**3.426**	**0.835**	**0.586 (R1) (0.000)**	-	
3. PROC5	**3.64**	**1.022**	**0.404 (R2) (0.002)**	**0.350 (0.010)**	-

5.2.2 Discussion: Research Avenue 2 – Factors affecting UPI

The findings reveal that both the processes and the culture are correlated with the level of understanding of project interdependencies, and that a project culture that is characterized by trust and promotes information sharing may have a particularly strong influence. The findings highlight that the tools and processes and the project culture and environment are both important factors in an organization's understanding of project portfolio interdependencies. This finding supports other research that emphasizes the strong relationship of culture and environment with PPM outcomes, and cautions against a focus on processes and tools in isolation (Christiansen and Varnes, 2008; Cooper et al., 2004; Kleinschmidt et al., 2007).

6. Conclusion and Future Research

This research contributes to and extends previous studies in two areas: the use of visual representations to support strategic decision making, and the development and application of methods and tools for the management of project interdependencies. In addition to the contributions to these bodies of research and literature, the findings also provide guidance for practitioners of PPM. It is generally accepted that organizations need to understand the interdependencies between projects in order to strategically manage their project portfolios. We have described two organizations' experiences with applying a new way of visually representing data to support decision making, and we have tested a conceptual model of the understanding of project interdependencies. This research has generated insights into how organizations may be able to improve their understanding of project interdependencies through two avenues of investigation.

First, we tested the use of VPM, a network mapping approach for the visualization of project interdependencies to support decision making. Findings indicate that VPM offers insights that can improve understanding, and that it has the potential to provide benefits by providing support for strategic decision making and as a communications tool.

Second, we explored the relationships in a proposed conceptual model on factors influencing organizational understanding of project interdependencies. The findings highlight the importance of both culture and process, and suggest that the culture factors may have more influence than the process factors on an organization's understanding of project interdependencies.

We emphasize that this is an exploratory study involving two organizations. Further research with other organizations and industries is required to verify or extend these findings and refine insights into the factors that affect an organization's understanding of project interdependencies.

The findings from the first research avenue suggest that network mapping approaches such as VPM may become one of the tools identified as useful for PPM. Further research is required to better understand whether and how such tools can enhance an organization's capability to manage its project portfolio, and how the visual network mapping representations can be best constructed, interpreted, and used in practice. This research used responses from project managers to develop the VPM displays; however, future research could consider whether other sources of knowledge about project interdependencies can be effectively used. In addition, future research should evaluate the effort required to create network mapping displays on a regular basis and the effectiveness of methods of updating the displays to represent dynamic project portfolio environments.

The conceptual model tested in the second research avenue is an exploratory model that could be extended to include a wider range of factors through future research. In addition to further culture and process factors, future research could also consider other dimension such as portfolio size and portfolio complexity. The exploratory work has employed some new item questions, and further work on the development of items and scales is recommended.

In conclusion, this exploratory research has introduced project network mapping as a visual representation tool for understanding the interdependencies in project portfolios. Our study indicates that network mapping has potential as a tool to assist with PPM and support strategic portfolio decision making;

however, the results also highlight that the culture and environment may be more important than the tools and processes. The findings suggest that managers need to pay attention to the project culture as well as the tools and processes. While seeking the best methods and tools to implement, they must also ensure that the culture and the project environment support the between-project communication and the capture and sharing of information that are required for best understanding of project interdependencies.

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