Visualising project interdependencies for enhanced project portfolio decision-making

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Abstract
Project management (PM) and project portfolio management (PPM) communities face challenges in the management of complex and highly interdependent project portfolios, as these interdependencies must be understood and managed for best project and portfolio outcomes. The research reported in this paper provides benefits to the global PM and PPM community by introducing a new tool and by providing insights into the factors affecting an organisation's ability to understand project interdependencies (PI). Visual project mapping (VPM), the creation of graphical displays of projects and their interdependencies as a network of nodes and arrows, is shown to provide benefits by supporting communication and strategic portfolio decision making. The research also highlights the importance of the environment and culture as well as processes and tools and indicates that they work together to improve an organisation's understanding of project portfolio interdependencies
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Keywords. Network Analysis, Social Network Analysis (SNA), Project Interdependencies, Complexity, Project Portfolio Management (PPM), Learning.

Introduction

Interdependencies between projects must be understood and managed for best project and portfolio outcomes. Project management (PM) and its close cousin, project portfolio management (PPM) are global professions that are continually developing and improving to cope with increasing complexity and dynamic environments. The research presented in this paper aims to help improve PPM capability by exploring the factors that influence how well an organisation understands its project interdependencies (PI) and by testing the use of a new network mapping method called visual project mapping (VPM).

In conjunction with PM, PPM approaches provide a holistic framework for the strategic management of the project portfolio to enhance the return from project investments. Project management practices are now used in a wide variety of industries, and are often the main organisational form for an increasing array of organisations [**1**]. PM and PPM are continually developing and improving, with global research projects and the development of worldwide standards and terminology facilitating the ability of globalised organisations to operate effectively across national

borders[1]. However, while the progress in the PM and PPM disciplines have improved global project management capabilities and performance, a large percentage of projects still fail. Research studies regularly report disappointing project success rates of between 30 and 60 percent [**2, 3, 4, 5**]. Therefore there is significant scope for improved project success rates, and organisations actively seek new methods that may boost the return on their project investments. In dynamic environments characterised by increasing complexity, resource constraints and globalised competition, organisations regularly invest in learning activities to develop and improve their PM and PPM capabilities [**6**].

PPM success factors

Projects are temporary endeavours undertaken to meet specific goals such as the development of new products or services or the implementation of organisational change [**7, 8**]. PPM processes help organisations manage their portfolios of innovation projects 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 [**9, 3**]. The literature suggests that the successful management of project portfolios extends beyond the processes, methods and tools. The organisational structure, people and culture are also important aspects of the overall PPM capability [**10**]. Research repeatedly shows that a PPM capability must be developed over time [**3, 11, 12**] and that although there are a range of methods and tools that are commonly used for PPM, they must be tailored to the individual environment for best results [**13**]. The proliferation of 'best practice' studies and maturity models highlights the relationship believed to exist between PPM maturity and improved outcomes [**14, 15, 16, 17**]. Similarly, the strong focus on processes and methods for PPM indicates the belief that these processes and methods can improve PPM outcomes [**18, 19, 20**], indeed empirical research provides evidence of some practices that are associated with improved outcomes [**3, 21, 22, 23**].

Interdependent portfolios and special challenges

The management of complex and highly interdependent project portfolios creates additional challenges that are not adequately addressed by current PPM tools and techniques. Interdependencies are acknowledged as important factors in PPM decision-making [**24, 25**]. 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 for scarce resources until they 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 [**26, 27, 28**].

[1] For example GAPPS, the global alliance for project performance standards is an international "volunteer organisation that provides a forum for stakeholders from differing systems, backgrounds, and operating contexts to work together to create performance based frameworks and standards that address the needs of the global project management community" (see www.globalpmstandards.org).

It is widely accepted that organisations must be able to understand the dependencies between projects in their portfolio in order to make appropriate project decisions for the best portfolio outcomes [**26, 27, 41**]. The literature on project management, learning and knowledge-sharing indicates that several aspects of the project environment may affect the ability for an organisation to understand and manage project interdependencies. Dependencies must be identified so that project decisions are made with the understanding of the possible flow-on effects to other projects in the portfolio. A combination of the right processes and the right environment is required to enable organisations to learn from past experiences and avoid reinventing the wheel [**33**].

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 [**29, 30**]. 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 organisation [**31, 32**]. 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 [**42**]. Post-project reviews or post-implementation reviews are often recommended for capturing project knowledge, however research indicates that such reviews are not regularly completed and that the transfer of the knowledge presents additional challenges [**33, 10**]. Methods for capturing both tacit and explicit knowledge and for transferring that knowledge must be highly customised to the particular project environment [**33**]. Organisations need to be able to capture, codify and share data from previous or concurrent projects [**42**] and to view that data from a portfolio perspective [**43, 44, 9, 3**].

Conceptual model

The literature indicates that the project environment and the processes used are both important for organisational understanding of PI. These process and environment factors are proposed to work together to improve the understanding and management of interdependencies between projects. Figure 1 presents a conceptual model based on the literature on PPM and the management of project interdependencies. Relationship R1 proposes that the establishment and use of processes for between-project communication and learning will be positively correlated with improved understanding of project interdependencies (UPI). Relationship R2 proposes that a project environment and culture that supports between-project communication and learning will be positively correlated with improved UPI. Relationship R3 identifies the belief that an improved UPI will lead to improved PPM performance.

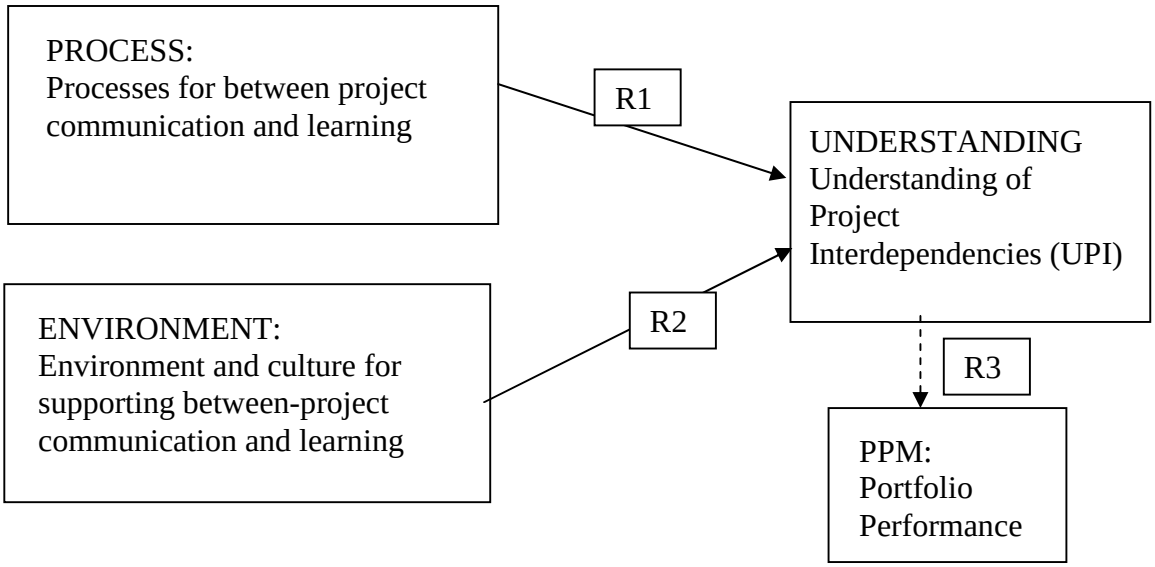

Figure 1: Conceptual model on factors influencing the understanding of project interdependencies.

PPM tools for managing project interdependencies

The ability to understand, communicate and manage interdependencies between projects is a challenging area for PM and PPM. Between-project communication is an important part of the solution and can be improved by management strategies [**45, 46**]. Resource dependencies can sometimes be managed by scheduling optimisation systems [**18**]; however these types of systems require large amounts of numerical input and are not considered useful in most PPM environments. Dependency matrices are a more common method that are used to provide a view of interdependence between projects [**47, 48**], however the matrix does not reveal accumulated or multi-level interdependencies and there is a need for more effective methods and tools for the management of project interdependencies, particularly indirect dependencies [**49**]. Research indicates that 'best practice' organisations make PPM decisions in meetings, and that graphical methods such as portfolio maps and other graphical and visual information displays facilitate the group decision-making [**23, 44, 50, 51, 41**].

Network mapping and analysis

Network mapping tools have the ability to map relationships between nodes in a network at multiple levels and to reveal accumulated effects [**52**]. The mapping is done through the use of software-based tools that help to record, analyse and visually display the relationships between items or 'nodes' in a network. Such maps facilitate enhanced analyses through modelling 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 [**53**].

Social network analysis (SNA) and the related organisational network analysis methods are a common application of network mapping where relationships between people or organisations are analysed and presented in a visual form [**54**]. 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 organisations [**55, 52, 56**], promoting collaboration, supporting critical nodes in the network, and managing and maintaining networks during organisational restructuring [**56**].

There are many other existing applications for network mapping. These include mathematical, biological and economic modelling [**53**]. Network mapping has also been used in conjunction with design structure matrix tools to manage interdependencies between tasks in product development environments [**57, 58, 59**]. Product development team interactions and information flows were measured in another study that demonstrated the use of network mapping and analysis in identifying the most important nodes in the network [**57**].

These studies show the benefits of network mapping for networks of teams or tasks involved in complex product development. These findings indicate that network mapping and analysis may have benefits for other similar applications such as the understanding of interdependencies across a complex project portfolio. Therefore, this research explores the use of network analysis methods to create a network map of a project portfolio through 'visual project mapping' (VPM). 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 2. There are many options for VPM displays, for example in Figure 2 the projects are sized according to the level of importance based on accumulated dependencies. Initial tests of the use of VPM indicate that network mapping and analsysis can be useful for project, program and portfolio management [**43**].

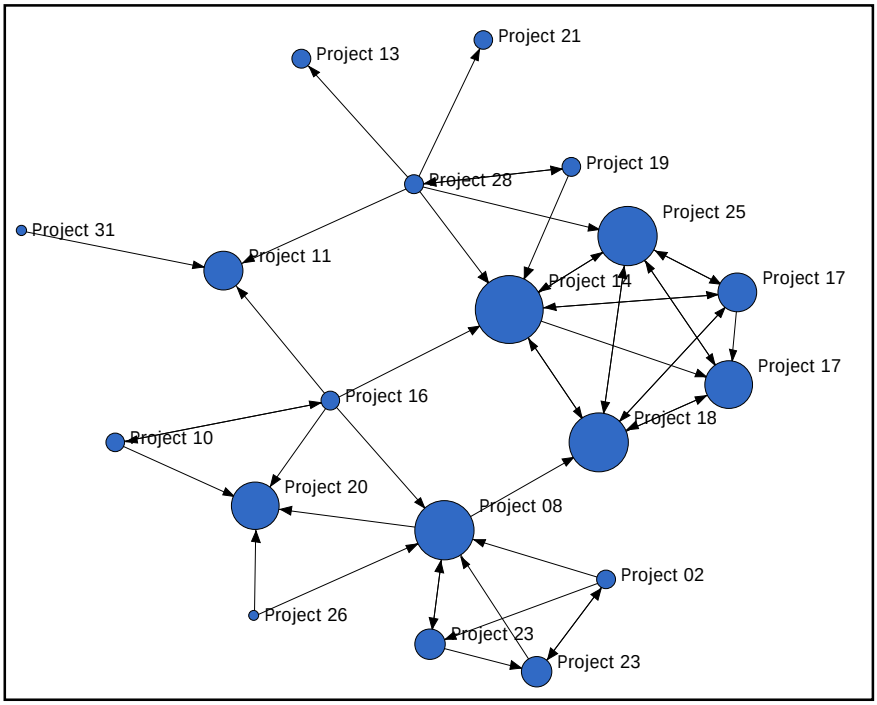

Figure 2: Example visual project map (VPM)

By highlighting the most important projects and revealing clusters of interdependence, VPM analysis provides valuable information about the relative influence and importance of projects that may not be readily apparent through traditional methods of analysing project interdependencies. VPM network maps also have the capacity to help organisations visualise multi-level dependencies by revealing the chain of dependencies in a clear visual format [**49**].

Methods

The exploratory study reported in this paper investigates the management of project interdependencies in complex project portfolio environments, defined as environments where there are multiple relationships or dependencies between at least 80 percent of the projects. The two avenues of research are; (1) the research tests the use of network analysis through VPM to improve understanding of PI, and (2) the research investigates the relationships between the project environment, the processes and UPI shown in the conceptual model in Figure 1.

A three-phase mixed method study was used to study two organisations with project portfolios containing multiple interdependencies. This research will extend to further organisations later in the year. The two organisations studied represent diverse project environments in the public (defence) and private (telecommunications) sectors. The selection of diverse organisations strengthens the ability to draw generalisations from the research and the ability to compare and contrast results between environments [**60**].

Semi-structured interviews and analysis of project and portfolio documents and information were used during the first phase to determine the organisational environment, the nature of the interdependencies and the bounds of the portfolio for the study. The second phase, the quantitative data collection phase, was customised based on input from the first phase so that the data collection instrument reflected the particular projects in the relevant portfolio and the types of dependencies experienced by that organisation. Project managers were asked to input data using the ONA Surveys survey tool[2]. The ONA Surveys tool was originally designed for the analysis of organisational networks and has been customised for this research to include a range of additional questions on the project environment. These variables, derived from factors identified in the literature review, are summarised in Table 1. The responses were captured using a Likert scale with rating descriptions as shown in Table 2. At the completion of the second phase, project interdependencies were mapped by VPM using network mapping and analysis tools [**61**], and the relationships on the conceptual model in Figure 1 were tested using SPSS statistical analysis of the project environment variables. The third and final phase of the study collected rich qualitative data at a semi-structured feedback session where the project maps were presented to senior project stakeholders. The data were then analysed to evaluate whether and how VPM affected the senior portfolio stakeholders' understanding of PI.

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

Table 1: Project environment 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 many of the interdependencies in the project portfolio other than those that affect my project

Findings and discussion

A large amount of qualitative and quantitative data has been collected and analysed. Due to the limited space available this paper provides only a brief summary of the initial findings from this exploratory research. The qualitative findings related to the

use of VPM are summarised first followed by the quantitative findings on the relationships in the conceptual model.

The qualitative data from the feedback sessions explored three main questions.

Are the VPM displays easy to interpret? The VPM displays use circles for each project and arrows to indicate which project depends upon another project as shown in Figure 2. For some managers the meaning of the direction of the arrow was not initially obvious, but with explanation it was felt to be clear and logical. The portfolio manager [p1] at the first organisation [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!" [Org2p1] and commented further that "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 maps can be presented in a number of formats and it was acknowledged that the best type of display would depend on each individual situation. Managers at Org1 suggested that if organisations were using VPM regularly it would be best to adopt a few standard formats so that the maps could be quickly and easily interpreted. This follows common PPM approaches where templates and standard formates for graphs and portfolio maps are developed and adopted to assist with analysis and comparison.

Were any new insights gained from the maps? Both organisations found new insights by viewing their project interdependencies in the VPM format. The maps provided some very powerful insights for Org2 in particular, prompting action on one project issue. Some of the insights were due to the fact that the maps presented information in a new way, making connections easier to 'see' ("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 were due to the fact that the data were collected from the project managers and provided information not previously available ("We have new information available here, that hasn't existed before to help us make decisions and justify actions" [Org2p2]). Other managers 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 project… and allow for the prioritisation of projects to show the risks in following through with a decision"[Org1p3].

Do you think the use of VPM could provide benefits to organisations? The main benefits in both organisations are related to communication and decision-making although the managers had different views of the relative benefits. For example at Org1, one manager sees the value of the maps mostly at the decision-making level because "they add rigor and transparency"[Org1p1], but another manger felt that the maps will be more useful for communicating the decisions than making the decisions [Org1p2]. At both organisations, the maps were felt to be 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. They were felt to be "Definitely a very good communications tool, REALLY good" [Org1p3] and very powerful for getting senior manager support with the "direct evidence" provided by the maps [Org2p2]. The

value of such maps was particularly strongly emphasised 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].

In summary, the qualitative findings from the feedback sessions indicated that the VPM displays helped illuminate the relationships between projects and provided new insights to the senior portfolio stakeholders at the two organisations. Both organisations thought that benefits from using the maps would come primarily from their use as decision-making and communication tools. Although both organisations 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 quantitative data based on the project environment questions were analysed to investigate relationships R1 and R2 on figure 1, however the relationship R3, between UPI and PPM performance, was not able to be tested with only two organisations in this initial study.

The project environment variables clustered into the three constructs identified in Table 3; UPI4, a construct containing 4 items related to the level of UPI, ENV5, a construct containing 5 items relating to the levels of trust and openness to support the sharing of information in the project environment, and PROC5, a construct containing 5 items relating to the processes used to capture and share project information.

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	**ENV5** 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. ENV5	3. PROC5
1. UPI4	**3.63**	**0.925**	-		
2. ENV5	**3.426**	**0.835**	**0.586 (R2) (0.000)**	-	
3. PROC5	**3.64**	**1.022**	**0.404 (R1) (0.002)**	**0.350 (0.010)**	-

Table 4 identifies the correlations between the identified constructs and highlights the relationships R1 and R2 from the conceptual model in Figure 1. While both are significant correlations, R2 is stronger than R1, indicating that the environment (ENV5) may have a stronger correlation with the level of UPI (UPI4) than the processes and procedures used (PROC5).

Conclusion

In order to strategically manage their project portfolios, it is generally accepted that organisations need to understand the interdependencies between projects. This research has generated insights on how organisations may be able to improve their understanding of PI in two areas. First, the use of VPM (the creation of graphical network maps of project portfolios) was tested. Findings indicate that VPM offers insights that can improve understanding, and that it can provide benefits as a decision-making and communications tool. Secondly, the relationships in a proposed conceptual model on factors influencing organisational understanding of PI were explored. The findings reveal that both the processes and the environment are correlated with UPI, and that a project environment characterised by trust and that promotes information sharing may have a particularly strong influence on UPI. These findings provide benefits to the global PM and PPM community by introducing a new tool to improve UPI and by highlighting the fact that the tools and processes and the project environment and culture work together to improve an organisation's understanding of project portfolio interdependencies.

The findings from this study should be considered keeping in mind that this is the first stage of an exploratory study involving two organisations. Further research with other organisations and industries is required to verify or extend these findings and to refine the insights on the factors that affect UPI.

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