Structuring Project Interdependencies into a Simple Graphical Hierarchical Model

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Abstract

Several methods and tools have been developed to support managing project portfolios. However, despite the increasing attention on project portfolio management (PPM) over the last decade from both academic and practitioners, very few methods and tools have been proposed for modeling dependencies among projects within a portfolio. For better visualizing interdependencies among projects, this paper proposes to apply interpretive structural modeling (ISM) for structuring project interdependencies into a simple graphical hierarchical model. For demonstration, this method is applied to a portfolio consisting of 22 interdependent projects.

Keywords
Projects portfolio management, project interdependencies, visual tools, interpretive structural modeling

1. Introduction

The project portfolio management (PPM) field has quickly grown in the research arena during the past decade. Levine (2005) defined PPM as "a set of processes, supported by people and tools, to guide the enterprise in selecting the right projects and the right number of projects, and maintaining a portfolio of projects that will maximize the enterprise's strategic goals, efficient use of resources, stakeholder satisfaction, and the bottom line."

Earlier PPM researchers have focused on the following areas: projects prioritization, project selection, risk management, and resource management. But, the management of projects interdependency requires additional research (Teller et al., 2012), since projects within a portfolio are not separately executed where they interrelate and have project interdependencies within the organization portfolio and are required to be studied and evaluated (Al Zaabi & Bashir, 2018; Killen & Kjaer, 2012; Rungi & Hilmola, 2011; Engwall & Jerbrant, 2003; Hamidovic & Krajnovic, 2005). Rungi (2010) conducted an empirical study on PPM practices within organizations and found higher rates of project success when organizations consider project interdependencies. However, Rungi and Hilmola (2011) found that organizations that have failed to reflect project interdependencies in their practices may cause cannibalization in their target market, which may lead to negative effects on the project portfolio's commercial success. Moreover, ignoring projects interdependencies in PPM practice can cause slippage in project schedules (Formentini & Romano, 2011) and unanticipated risk changes (Sanchez et al., 2009), which may threaten the portfolio balance between the following estimated project parameters: project time, risks, and anticipated profits.

The definition of project interdependencies has been given in the previous literature in different and diverse ways. However, it can be classified overall into five categories as follows: resource, market, knowledge, outcome, and benefit interdependencies.

- Resource interdependencies arise due to resource sharing and allocation demands among different projects, including technology. Staudenmayer (1997) claimed that resource interdependencies are found in three conditions: resource demand presence, resource limited availability, and inadequate resources allocation. Blichfeldt and Eskerod (2008) argued that resource interdependency is the most important interdependency type in PPM and obtains the highest consideration overall from portfolio managers in comparison to the remaining types of project interdependencies.

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- Knowledge interdependencies exist when a project generates knowledge and expertise and subsequently receives benefits from other projects within a projects portfolio. For instance, staff members dealing with parallel projects may cooperate to provide solutions for problems that are common in entire projects (Teller et al., 2012). When technology-related knowledge diffusion does not happen, the unexpected risk of "reinventing the wheel" arises, causing an organization to waste resources (Rungi & Hilmola, 2011). However, Verma and Sinha (2002) placed emphasis on technology interdependency, whereas Killen and Kjaer (2012) focused on learning interdependency.
- Market interdependencies happen when a recent product is launched in an existing product market or when knowledge of the current market is utilized for a product that is under development (Verma & Sinha, 2002). Rungi and Hilmola (2011) argued that the previously mentioned interdependencies also arise when different projects within a portfolio contend for attention as they evolve from matching or similar strategies or goals.
- 4. Outcome interdependency occurs when a project is in need of other project results (Teller et al., 2012; Killen & Kjaer, 2012).
- Benefit interdependencies arise when an organization profits dramatically increase due to the synergy of executing two or more interdependent projects.

This paper has been structured as follows: It starts with an introduction about PPM and project interdependencies, followed by a literature review on existing PPM methods and their limitations. Then, an interpretive structural modeling (ISM) model is developed based on 22 example project portfolios. It ends with discussions on the ISM outcome, managerial implications, and future scope.

The aim of this study is to propose a simple model to visualize and understand project interdependencies based on ISM to overcome the shortcomings of existing PPM visual tools.

2. Literature review

Different PPM methods and tools have been established to manage interdependencies between projects and can be categorized as optimization or visual tools (Al Zaabi & Bashir, 2018; Ghapanchi et al., 2012; Eilat et al., 2006; Disckinson et al., 2001). Optimization methods usually deal with resource interdependencies; however, optimizations require huge inputs of numerical data, so they are described as disadvantageous within several project portfolio environments (Rungi, 2010; Coldrick et al. 2005). Visual tools are implemented for illustrating the interdependencies between projects, and they consist of project roadmaps, nested option models, dependency matrices, and network maps.

Project roadmapping is an abstract mapping model that produces detail overload (Cooper et al. 1999), whereas large project portfolios cannot be modeled by nested option models (Rungi, 2010). A dependency matrix method is a widely used method that is utilized to produce an interdependency overview among projects within a portfolio (Teller et al., 2012), but it cannot identify accumulated or multilevel project interdependencies. As a solution, Killen and Kjaer (2012) proposed to visualize project interdependencies within a portfolio by developing a visual project mapping (VPM) method in which each project is visualized as a node in a network, and directional arcs are presented to illustrate the interdependencies. As an illustration, an arc directed from node x to node y represents that project x depends on project y. Arc colors and weights represent a project's interdependency type or strength. The main advantage of VPM is the capability to visualize interdependency between projects/nodes in a portfolio/network at different levels and to display multilevel or accumulated interdependencies. Killen (2013) tested the usefulness of VPM by comparing dependency matrices and tabular lists of dependencies by conducting a controlled experiment in which students evaluate the provided data, evaluate projects interdependencies, and avoid killing interdependent projects while reducing a portfolio's estimated budget by 10%. The experiment data included 26 projects and their interdependencies. This experiment revealed that the usage of project visual mapping interdependencies, especially VPM, produce better insight of the interdependencies between projects within the complex environment of project portfolios, which should result in better decisions. VPM can provide snapshots of the interdependencies between projects without classifying key project interdependencies. Thus, it hard to identify key activities or interdependencies from VPM.

To overcome the shortcomings of the earlier PPM visual tools, a simple model was developed in this study to visualize and understand project interdependencies by employing.

3. ISM methodology and model development

One way to convert the complex graph used for visualizing project interdependencies into a simpler graphical hierarchical graph is to use ISM.

In 1973, Warfield proposed an ISM method to analyze socioeconomic systems in a complex environment. The ISM method allows researchers to establish a diagraph to display complex interdependencies among different elements that exist within a complex environment. The ISM concept utilizes the knowledge and experience of experts to break down a complex system to certain components and then build a multilevel hieratical model. The method is often used to produce a root-cause understanding of a complex system and to produce a course of action to solve a problem. Several scholars have applied the ISM method to demonstrate relationships complexity direction and order between system elements. Shibin et al. (2016) used ISM to build a theoretical framework of the enabler and barrier interdependencies of flexible green supply chain management. Venkatesh et al. (2015) produced an ISM model to analyze the risk of a supply chain. Sivaprakasam et al. (2015) developed a model for analyzing the criteria and sub-criteria involved in the implementation of green supply chain management using an ISM framework. Jadhav et al. (2014) used ISM to understand the complexity of interdependencies in sustainable lean implementation in the automobile sector.

The technique is used as a learning process for the managerial level, enabling an improved understanding of the system under study. The methodology of ISM includes five main steps:
1. Identifying projects and their interdependencies.
2. Developing a structural self-interaction matrix.
3. Constructing a reachability matrix
4. Partitioning the reachability matrix,
5. Forming the ISM-based model.

To illustrate the benefit of modeling interdependencies between projects within a portfolio, the selected ISM methodology was implemented in a project portfolio including 22 projects with their interdependencies. Table 1 shows the interdependences between the 22 hypothetical projects within a portfolio in tabular format.

Table 1: Example in tabular format for twenty-two projects and their interdependencies

Project	Projects dependent upon	Project	Projects dependent upon
A	A,B,I,K,O,W	N	G,N
B	A,B,K,O	O	A,B,K,I,N,O
C	C,Y	P	H,P,R
E	E,T	Q	Q
F	F,P	R	R
G	G,N	T	T,Z
H	H	U	F,N,T,U
I	A,B,K,I,O	W	C,J,N,Q,W,Y
J	C,J,W	X	G,N,Q,W,X
K	A,B,N,K,O,T,Z	Y	C,J,Y
M	M,T	Z	T,Z

3.1 Structural self-interaction matrix

The interdependencies between the 22 projects are represented in table 1. It is observed that this diagraph maps the mental picture of the problem with its fundamental system. A systematic methodology can be implemented to further simplify and rearrange it. This methodology calls for translating the graph into a structural self-interaction matrix (SSIM). The SSIM can be utilized to construct a hierarchical restructuring of the graph. After constructing, a binary matrix is produced from SSIM, which is called the direct relationship matrix. In the example portfolio, the reachability matrix was built based on table 1.

The initial reachability matrix, which is based on the above guidelines and produced by implementing transitivity links, is presented in Table 2. Therefore, when project A is related to B and B is related to C, project A is accordingly related to project C.

Table 2: Initial direct relationship matrix

Project	A	B	C	E	F	G	H	I	J	K	M	N	O	P	Q	R	T	U	W	X	Y	Z
A	1	1	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0
B	1	1	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0
C	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0
E	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
G	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
H	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
I	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0
K	1	1	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
N	0	0	0	0	0	1	0	0	0	1	0	1	1	0	0	0	0	1	1	1	0	0
O	1	1	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0
P	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Q	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0
R	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
T	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	1	1	0	0	0	1
U	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
W	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0
X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Y	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
Z	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1

3.2 Level partitions

The reachability matrix is then partitioned by revealing the reachability and antecedent sets for each project. The reachability set includes the project itself and other projects on which it might depend, while the antecedent set includes the project and other projects that it may depend upon. The next step is to intersect the two sets for all projects. The project(s) where the antecedent set and intersection set are equal is(are) at the bottom level of the ISM hierarchy model. After identifying the bottom level projects, they are separated from the rest of the projects. This step is iterated to find the next higher level of projects. The partitioning step is finalized when the highest level of projects is obtained. These produced levels are utilized to help build the graph and the final model. In this study, this step was achieved in five iterations. Tables 3 and 7 show the projects, with their following reachability sets, antecedent sets, intersection sets, and levels for each performed iteration.

It is worth noting that the initial reachability matrix, which is the main input to ISM, is simply the transpose of a dependency matrix. Therefore, an additional advantage of using ISM for modeling project interdependencies is that all the applications of dependency matrices that have been reported in the literature can be easily implemented by adding a simple addition step, specifically matrix transposition.

Table 3: Iteration 1

Project	Reachability set	Antecedent set	Interaction set	Level
A	A,B,I,K,O,W	A,B,I,K,O	A,B,I,K,O	I
B	A,B,K,O	A,B,I,K,O	A,B,K,O	
C	C,Y	C,J,W,I	C	
E	E,T	E	E	I
F	F,P	F,U	F	
G	G,N	G,N,X	G,N	
H	H	H,P	H	
I	A,B,K,I,O	A,I,O	A,I,O	I
J	C,J,W	J,W,Y	J,W	
K	A,B,N,K,O,T,Z	A,B,I,K,O	A,B,K,O	
M	M,T	M	M	I
N	G,N	G,K,N,U,W,X	G,N	
O	A,B,K,I,N,O	A,B,I,K,O	A,B,K,I,O	I
P	H,P,R	F,P	P	
Q	Q	Q,W,X	Q	
R	R	P,R	R	
T	T,Z	E,K,M,T,U,Z	T,Z	
U	F,N,T,U	U	U	I
W	C,J,N,Q,W,Y	A,J,X,W	J,W	
X	G,N,Q,W,X	X	X	I
Y	C,J,Y	C,W,Y	C,Y	
Z	T,Z	K,T,Z	T,Z	

Table 4: Iteration 2

Project	Reachability set	Antecedent set	Interaction set	Level
B	B,K	B,K	B,K	II
C	C,Y	C,J,W	C	
F	F,P	F	F	II
G	G,N	G,N	G,N	II
H	H	H,P	H	
J	C,J,W	J,W,Y	J,W	
K	B,N,K,T,Z	B,K	B,K	II
N	G,N	G,K,N,W	G,N	
P	H,P,R	F,P	P	
Q	Q	Q,W	Q	
R	R	P,R	R	
T	T,Z	K,T,Z	T,Z	
W	C,J,N,Q,W,Y	J,W	J,W	II
Y	C,J,Y	C,W,Y	C,Y	
Z	T,Z	K,T,Z	T,Z	

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Table 5: Iteration 3

Project	Reachability set	Antecedent set	Interaction set	Level
C	C,Y	C,J	C	
H	H	H,P	H	
J	C,J	J,Y	J	
N	N	N	N	III
P	H,P,R	P	P	III
Q	Q	Q	Q	III
R	R	P,R	R	
T	T,Z	T,Z	T,Z	III
Y	C,J,Y	C,Y	C,Y	III
Z	T,Z	T,Z	T,Z	III

Table 6: Iteration 4

Project	Reachability set	Antecedent set	Interaction set	Level
C	C	C,J	C	
H	H	H	H	IV
J	C,J	J	J	IV
R	R	R	R	IV

Table 7: Iteration 5

Project	Reachability set	Antecedent set	Interaction set	Level
C	C	C	C	V

3.3 Building the ISM model

The portfolio network shown in figure 1 and 2 was modeled by using a Social Network Visualizer (SocNetV). The example is presented in an existing PPM visual tool introduced by Killen and Kjaer (2012). The result of the VPM graph is shown in figure 2. VPM provides a complete picture of projects and their interdependencies, but it is hard to interpret the key projects and analyze or cluster them. However, the ISM-based model for the same data shown in figure 1 provides a simple graph for the whole portfolio and a structured graph that can be incorporated with what if scenario sessions.

Note that, in ISM, a directed arc from A to B means project B depends on A, whereas in Killen's VPM tool, a directed arc from A to B means project A depends on B, which is opposed to the traditional flow. Moreover, the circles or nodes illustrating each project may be sized based on the level of accumulated dependencies or other project characteristics.

The ISM was formed based on SSIM, and each project is plotted in figure 1, from which the projects can be organized to five levels.

1. The first level projects M, E, U, X, A, I, and O are placed in the bottom level or root level, since they have relatively more importance in term of interdependency.
2. The second level projects are F, G, W, K, and B.
3. The third level projects are T, P, N, Y, Q, and Z.
4. The fourth level projects are H, R, and J.
5. The fifth level project C has the lowest relative importance in term of interdependency.

Decision makers should pay particular attention to the bottom level, middle level, and then the top level projects for the following reasons:

- Cancelling, delaying, or significantly altering any one of the bottom level projects will have negative effects on many projects in the portfolio.
- Middle levels projects are relatively difficult projects to manage, since they depend on many other projects, while many other projects depend on them at the same time.
- Top level projects do not have much interdependency within the portfolio

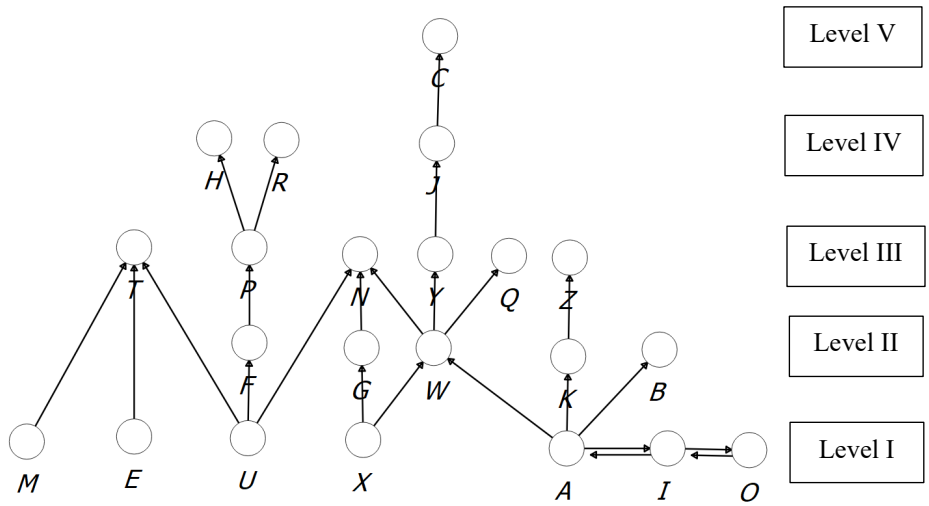

Figure 1: ISM based model for the example portfolio

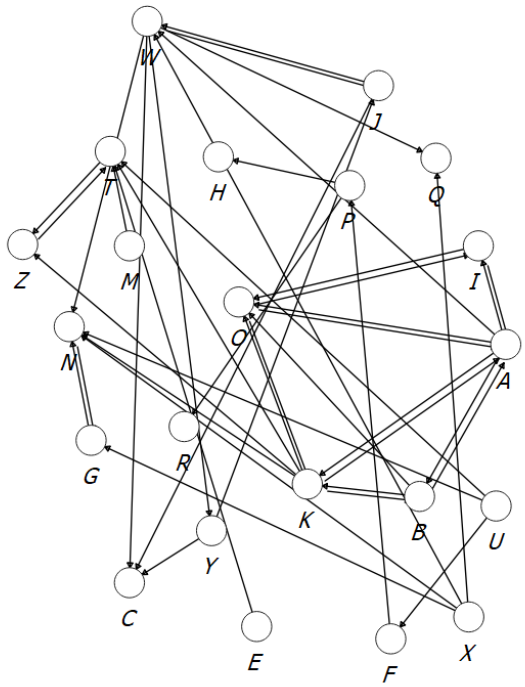

Figure 2: Portfolio network based on VPM

4. Conclusion

Investigating interdependency between projects is a challenging field in PPM practice. Optimization models and visual tools are considered methods and tools that utilize interdependencies within a portfolio. Visual PPM tools are believed to illustrate a better understanding of the interdependencies between projects. However, the existing PPM visual tools have some drawbacks relating to project roadmaps, the dependency matrix, the nested options model, and visual project maps. Project roadmapping is a basic model to visualize projects and produce detail overload. While the nested options model is valid for small project portfolios, the dependency matrix does not present multilevel or accumulated project interdependencies. Moreover, visual project mapping is often very complex, and it is difficult to trace the interdependencies among the projects.

To overcome these limitations, the ISM is implemented in this study to convert the complex graph used for visualizing project interdependencies into a simpler graphical hierarchical graph. The benefits of using the ISM methodology were presented through an illustrative example of a project portfolio consisting of 22 interdependent projects.

The ISM methodology arranged the projects in a hierarchical structure model including five levels that was simpler than VPM. The ISM model arranges the bottom level of the hierarchy (projects: M, E, U, X, A, I and O) as the more important projects based on their interdependency within the portfolio. The outcome of the ISM model can help decision makers to pay attention to bottom level, middle level, and then top level projects. Cancelling, delaying, or significantly altering any one of the bottom level projects will have negative effects on many projects in the portfolio. Moreover, middle level projects are the most difficult projects to manage, since they depend on many other projects, while many other projects depend on them at the same time. Top level projects do not have much interdependency within the portfolio.

Finally, in addition to the ISM model used in this study, other methods would likely be useful for understanding the interdependencies of a project portfolio. The other methods could be used as complementary tools along with the ISM method for analyzing interdependences from different perspectives. This could be explored in a future study.

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