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Handling project dependencies in portfolio management

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Abstract

Although construction is a project-based industry, management focus has recently shifted from projects to project portfolios to meet strategic objectives of companies that require holistic analysis of the projects undertaken. Dependencies between projects within a portfolio need to be taken into consideration since they may significantly affect the portfolio success with their combined effects. There are limited studies in the area of construction project portfolio management that investigate how the dependencies between projects can be handled. In this paper, a method is presented to calculate and visualize project dependencies to support decision making process within a portfolio management tool for construction projects. Within this context, a dependency map is proposed not only to identify different dependencies and their effects within the portfolio, but also to take into consideration the combined effect of dependencies. An illustrative case study is depicted in the paper to demonstrate how the proposed method works and how its results can be used to support decision-making during portfolio selection.

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Keywords: decision support system; network analysis; portfolio management; project dependencies; visualization.

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1. Introduction

Construction is a project-based industry. The unit of analysis and focus of decision-making (bidding, risk assessment, etc.) are the "projects". During decision-making, construction projects are generally handled as they are independent from each other and the decision support tools are usually designed to be used at the "project level". However, most of the companies are executing projects simultaneously and there exist dependencies between these projects due to shared resources, similar technical requirements, physical locations, contractual agreements and similar external environment. When a project success is dependent on other projects, it can be stated that relationship exists between these projects[1]. Projects may share many resources and may have common objectives to be achieved. Therefore, there can be a resource, outcome, market/benefit, financial, or learning dependency between projects[2]. Thus, projects need to be handled from a "portfolio" perspective and managed at the "portfolio level" as it has been widely discussed in the literature[3,4,5]. Although, research on portfolio management has been widely carried out in the industries such as finance and regarding projects such as technology, innovation, and research and development projects; construction industry specific studies have been very limited in this area[6,7,8]. Portfolio success is considerably dependent on identification of relations between projects and generation of strategies accordingly[2,4,9]. In his study, Rungi (2010a)[5] states the importance of evaluation of dependencies between projects to achieve portfolio success and argues that interdependency management is a critical success factor. Portfolio management is a complicated process since it requires comprehensive analysis of strategic objectives, financial profit, project performance, demand conditions, resources, capabilities, risks and other similar parameters[10,11]. Thus, methods and tools are required for facilitating portfolio management process as it is widely emphasized in the literature[11,12,13]. This paper is a part of a research project conducted to develop a portfolio management tool for construction companies. A visual, intelligent (capable of generating and using knowledge), and dynamic (capable of updating) tool has been designed, which also enables identification and visualization of project dependencies. It has been generated at the end of an iterative process through feedbacks obtained by interaction with academicians and construction company professionals, and has been coded by a professional software company. The tool has a potential to provide decision support in the management of risks and resource allocation, also facilitates learning from projects based on the identified project dependencies. In this paper, we will present the quantification method used for project dependency assessment in this tool.

2. Research background

In order to improve portfolio performance, dependencies between the projects must be absolutely taken into consideration in the identification and evaluation processes[2,5]. Importance of dependency evaluation between projects is considerably mentioned in literature; however, a comprehensive study focused on evaluation of dependencies has not been published yet[14].

Various types of dependencies can be present between the projects. *Resource dependency* can be explained as a limitation where resources are used jointly in another project or constraint to starting/ending of projects. *Market/interest dependency* represents the complementary/competitive effects of projects for each other. *Product dependency* implies a technical requirement or any other product/return is expected from another project. *Learning/experience dependency* is about the knowledge to be obtained in one project is to be used in another project. Lastly, *financial dependency* exists when there are financial relationships between projects. Rungi (2010b)[15] underlines that analysis of dependencies within portfolios has contributions in effective portfolio selection and portfolio success. However, in the same study he has shown that although companies are generally aware of the existence of inter-project interactions, they do not include them in their evaluations since they believe that the analysis and evaluation of relations are difficult and time consuming. The existing studies on dependency analysis usually consist of subjective evaluations as self-reporting methods, optimization methods, and visual representation methods[5]. The visual methods contribute to a more realistic view for evaluation of portfolios; however, they still have some limitations. Dependencies of projects are generally depicted through 2x2 matrix representations; however, these representations are not capable of reflecting multi-level dependencies between projects. They are capable of pairwise dependency analysis between projects and not capable of representing accumulated effects between projects. For example; in case of a dependency of project A to B, and Project B to C; this method is not able to evaluate the effect of Project A to C[1]. Methods that will be capable of quantification of dependencies between projects and inclusion of these in decision support systems are crucial[16].

Killen and Kjaer (2012)[1] propose a method, which is entitled as Visual Project Mapping (VPM) method, to provide the evaluation of accumulated and multi-level dependencies between projects by constructing network maps. VPM enables visualization of dependencies through “nodes” as projects and “arrows” between them as relations. These network maps generally have the ability to record, analyze, and represent the relations graphically. The network maps can provide more realistic evaluation of relations when compared to existing matrix representations[17]. Network maps constitute the basis of many decision support systems; however, they are not incorporated in portfolio management tools yet. Killen and Kjaer (2012)[1] conducted a preliminary study and present dependencies within a portfolio of projects using a network map. They categorize the dependencies as “less important”, “important” and “critical” considering the level of importance. Additionally, they define dependency types as “outcome”, “learning”, “resource” and “other”. They finally construct a representational network map and validate the capability of its use in dependency management of portfolios by company professionals.

3. Methodology used for handling dependencies in portfolio management

The project portfolio management tool has been designed to involve three types of projects as “completed projects” (where the lessons learned can be retrieved), “on-going projects” as the projects being executed and “potential projects” that the company is considering to bid/undertake. The dependencies are identified between “on-going” and “potential” projects only and used in the process of portfolio risk assessment. The tool helps generation of different scenarios and alternative portfolios are evaluated considering the risks, strategic fits and expected profitabilities. Within this context, a method has been generated to automatically calculate dependencies between projects, visualize them, and numerically integrate them to portfolio analysis process. The method provided by Killen and Kjaer (2012)[1] has been taken as the basis where the dependencies within portfolios are visualized through network maps. Differently from this study, an automatic calculation process for dependencies and their accumulated effects is provided. Additionally, the network map is improved with some additional properties for visualization. The details of the methodology is presented in the following sections.

3.1. Identification of different types of dependencies

Following the literature review, different types of dependencies have been identified and the “importance” of each type of dependency within “the portfolio risk” was obtained by a questionnaire study. The question for dependencies is held under “risk assessment” section of the questionnaire, which also includes sections for identification of measurements for functions as “strategic” and “similarity” assessments required for the tool. The questionnaire was distributed online to 280 construction professionals working in Turkish construction companies and 108 responses were obtained.

The identified dependencies specific to construction projects are categorized as follows[1,9]:

- *Financial dependency*: Dependencies that exist due to dependency on the same financial factors (e.g., problems with a client in one project may affect the other project with the same client).
- *Resource dependency*: Dependencies that exist due to sharing the same resources (e.g., any failure/inconveniency in special equipment used in one project may affect the other project that is using the same equipment).
- *Learning dependency*: Dependencies in contribution to learning between the projects, which have similar context/content that may improve the knowledge across the projects (e.g., problem that affects the knowledge gained during execution of a new process in one project may affect the other project that the same new process is being used).
- *Outcome dependency*: Any type of dependency that may imply an outcome or success dependency is defined as outcome dependency. If the outcome produced in one project is to be used in the other project, there exists an outcome dependency between the projects. Additionally, any special dependency may be defined with an outcome dependency to provide flexibility to the user (e.g., when a special condition is required for wining of a project, namely awarding of a project is dependent on successful completion of a project with the same client).

3.2. Measuring dependencies

"Overlap" similarity measure is taken into consideration in the identification and measurement of dependencies. The process is based on identification of categorical data similarities using project attributes, simply the number of matching attributes between two projects[18]. Attributes for each dependency have been identified considering the similarities as the causes of the dependencies. The following attributes and their corresponding weights are taken into consideration (Table 1). The "overall weights" are used to consider the importance of each dependency in the overall dependency between projects. Importance of each attribute in the measurement of dependencies are identified as "attribute weights". Once the user defines projects within the tool, dependencies are automatically calculated using the project data except for the "outcome dependency". User is asked to assign and quantify the "outcome dependency" while entering project information and only the critical resources are entered for identification of "resource dependency".

By using the attributes and the given weights, overall dependency between the projects {X, Y} as D(X, Y) are calculated according to the following formulae:

$$D(X,Y)\ [0{,}100\%] = \sum_{i=1}^{4} D_i\,(X,Y) * w_i \quad i = \{dependency\ types\} \tag{1}$$

$$D_i(X,Y) = \sum_{k=1}^{n_k} w_k * S_k(X_k, Y_k) \tag{2}$$

$$S_k(X_k, Y_k) = \begin{cases} 100\% & if\ X_k = Y_k \\ 0 & otherwise \end{cases} \quad k = 1, \dots, n_k \tag{3}$$

where; X and Y are projects, $D_i\,(X,Y)$ is the dependency measure for dependency i, w_i is the overall weight for dependency i, w_k is the attribute weight for attribute k, $S_k(X_k, Y_k)$ is the per-attribute similarity, and n_k is the maximum number of the attributes for measuring dependency i.

Table 1. Weights and attributes of dependencies.

Dependency Type	Overall Weight	Attributes to Measure	Attribute Weight
Financial Dependency	0.271	Client	0.533
		Currency	0.467
Resource Dependency	0.270	Personnel	0.279
		Manpower	0.245
		Machinery and Equipment	0.256
		Material	0.220
Learning Dependency	0.223	Country	0.154
		Project Type	0.157
		Client	0.133
		Technology	0.150
		Contract Type	0.135
		Project Delivery System	0.141
		Partnering Company	0.130
Outcome Dependency	0.237	-	-

3.3. Visualizing dependencies

After determination of types and magnitudes of dependencies between projects in a portfolio, a visual network map is generated. The map consists of "nodes" indicating the projects in the portfolio and "bi-directional relations" for depiction of the dependencies. The nodes are represented in different colours for "on-going" and "potential" projects. In addition, the nodes of more central projects (having higher interconnectivity) are relatively bigger in size. Dependencies are visualized in different colours to indicate different types of dependencies and with different thicknesses indicating the relative magnitudes of dependencies. Thus, the user can easily capture the information about the dependencies between the projects, understand the relative importance of different types of dependencies and identify critical projects by looking at the network map.

3.4. Incorporating dependencies within the risk assessment of project portfolios

The portfolio management tool is capable of evaluating the impact of any project candidate (potential project) to the existing portfolio by conducting scenario analysis. The effect of the project in question is depicted in terms of different types of dependencies. It is argued that the portfolio success can be increased by utilization of the tool that can facilitate resource management of the projects considering the “resource dependencies”, risk assessment by considering the effect of “financial dependencies” and fostering learning between projects. With the visual portfolio map, relationships between projects are automatically determined by the tool and suggestions on how this portfolio could be managed are to be provided. The tool may direct the user to proceed the planning process of dependent projects together, to concentrate on learning opportunities between similar projects, and to assess level of risk considering dependencies between projects. For example; based on the definition of “critical relationships”, the tool may warn the user to make the time planning/scheduling of the projects “A”, “B” and “C” together, to concentrate on the effective transfer of lessons learned between the projects “D” and “F”, to consider the projects “E” and “G” together in developing the risk management plans. The relation that has the highest magnitude within the portfolio is identified as the “critical dependency” between all dependencies and may indicate that this dependency needs attention. The critical projects and the intensity of dependencies can already be identified using the network map; or they can also be quantified by using the below formulae:

$$P_C(X)\ [0,100\%] = \frac{\sum_{i=1}^{n_p} D(X,Y_i)}{\sum_{i=1}^{n_p} D(X,Y_i) + \sum_{i<j} D(Y_i,Y_j)} \quad Port = \{X, Y_1, \dots, Y_{n_p}\} \tag{4}$$

where; $P_C(X)$ is the centrality of the project X, $\sum_{i=1}^{n_p} D(X,Y_i)$ is the total dependency of the Project X, $\sum_{i=1}^{n_p} D(X,Y_i) + \sum_{i<j} D(Y_i,Y_j)$ is the total dependencies between the projects of the portfolio $\{X, Y_1, \dots, Y_{n_p}\}$.

$$Port_{ND}\ [0,1] = \frac{\sum_{i<j} D(X_i,X_j)}{\binom{n_p}{2} * 100\%} \quad Port = \{X_1, \dots, X_{n_p}\} \tag{5}$$

where; $Port_{ND}$ is the network density of the portfolio, $\sum_{i<j} D(X_i,X_j)$ is the total of dependencies between the projects of the portfolio $\{X_1, \dots, X_{n_p}\}$ and $\binom{n_p}{2}$ is the possible dependencies of the network as binary combination count of the projects in the portfolio.

Centrality of a project indicates the “criticality of a project” in a portfolio, whereas density of a network indicates the “complexity of a portfolio” between different portfolio alternatives. Project centrality is based on the ratio of dependencies of a project to the total dependencies in a portfolio, and network density is based on the ratio of “actual connections” to “potential connections” in the network.

After the identification of critical dependencies, projects and networks; the accumulated/total effect of dependencies is taken into account during portfolio risk assessment. The effect is reflected to the average risk scores obtained by individual risk assessments carried out for each single project in the portfolio.

$$Port_R\ [0,100] = \bar{X}(P_R) * \frac{1 + Port_{ND}}{2} \tag{6}$$

where; $Port_R$ is the portfolio risk and $\bar{X}(P_R)$ is the average risk score of the projects in the portfolio.

Thus, the accumulated/total effect of the dependencies between the projects in a portfolio has been calculated and presented to the decision maker both by visual aids and quantitative measures to support decision-making process.

4. An illustrative example

A portfolio example can be given as follows. The numerical example prepared using “Excel” is utilized to demonstrate how the procedure works and maps are obtained using the “ORA Software” provided by Carnegie Mellon University to produce the expected maps. The information depicted in Table 2 is used for this purpose.

Table 2. Project information.

Properties	Project 1	Project 2	Project 3	Project 4
Status	On-going	On-going	On-going	Potential
Risk Scores	28.78	40.21	54.11	53.78
Financial Dependency Attributes				
Client	CL1	CL2	CL3	CL2
Currency	CU1	CU1	CU2	CU1
Resource Dependency Attributes				
Personnel	PE1		PE1, PE2	PE2
Manpower	-	-	-	-
Machinery and Equipment	-	ME1	-	ME1
Material	-	MA1	-	MA1
Learning Dependency Attributes				
Country	CO1	CO2	CO3	CO2
Project Type	PR1	PR2	PR3	PR2
Client	CL1	CL2	CL3	CL2
Technology	T1	T2, T3	T4	T4
Contract Type	-	CT1	CT2	CT1
Project Delivery System	PDS1	PDS2	PDS3	PDS3
Partnering Company	-	PCO1	PCO2	PCO1
Outcome Dependency	-	P4: 100%	-	P2: 100%

The calculated dependencies according to the matching of given project information are given in Table 3.

Table 3. Calculated dependencies between the projects.

Projects		Formula	P2				P3				P4			
			FD	RD	LD	OD	FD	RD	LD	OD	FD	RD	LD	OD
P1	Dependency (%)	(2)	46.70	-	-	-	-	27.90	-	-	46.70	-	-	-
	Dependency in Overall (%)	(2)* w_i	12.66	-	-	-	-	7.53	-	-	12.66	-	-	-
P2	Dependency (%)	(2)					-	-	-	-	100.00	47.60	70.90	100.00
	Dependency in Overall (%)	(2)* w_i					-	-	-	-	27.10	12.85	15.81	23.70
P3	Dependency (%)	(2)									-	27.90	29.10	-
	Dependency in Overall (%)	(2)* w_i									-	7.53	6.49	-

Using the identified dependencies, the network map is generated in the following format (Figure 1).

According to the results, the measures required for further analysis are calculated as follows (Table 4):

Table 4. Calculated measures for the projects and the portfolio.

Measures	Formula	Projects/Portfolio			
		Project 1	Project 2	Project 3	Project 4
Total Dependencies	$\sum_{i=1}^{n_p} D(X, Y_i)$	32.84%	92.12%	21.56%	106.14%
Centralities	(4)	26.00%	72.92%	17.06%	84.02%
		Portfolio			
Network Density	(5)	0.21			
Portfolio Risk	(6)	26.76			

According to the results, the most critical project is found as the "Project 4" (the potential project) with the centrality value of "84%". The decision maker should consider this project as a highly dependent project. The critical dependencies between the "Project 4" and "Project 2" should also be considered. The figures obtained for the portfolio as "network density" and "portfolio risk" can be used to compare different portfolio alternatives. The following warnings can be provided by the tool or decision-maker can make following conclusions for this specific example:

- Dependency network of the projects in the portfolio is at a critical level, therefore investigation of the dependencies between projects and attention to these dependencies during management of the projects are suggested.

- Due to centrality of the "Project 2", "Project 4" in the portfolio, these projects may significantly affect the value of the portfolio.
- Profitability is dependent on "CU1" at 86.31%. Fluctuations in this currency would affect the portfolio significantly.
- Profitability is 56.54% affected by the Client: "CL2". High dependency of the portfolio profitability to this client entails financial risk.
- The "Project 2", "Project 4" in the portfolio are sharing the same critical material "MA1", therefore careful procurement and planning of this material is suggested.
- The "Project 2", "Project 4" in the portfolio, are using the same machinery/equipment of "ME1", therefore scheduling should be carried out considering this limitation.
- The same personnel "PE1" has been assigned to the "Project 1", "Project 3" in the portfolio, therefore revision of the workload and consideration of the possible problems are suggested.
- The same personnel "PE2" has been assigned to the "Project 3", "Project 4" in the portfolio, therefore revision of the workload and consideration of the possible problems are suggested.
- There is high learning dependency/opportunity between the projects "Project 2", "Project 4" in the portfolio, consideration of knowledge transfer opportunity between these projects is suggested.
- Successes of the "Project 2", "Project 4" in the portfolio are dependent to each other, management attention is needed.

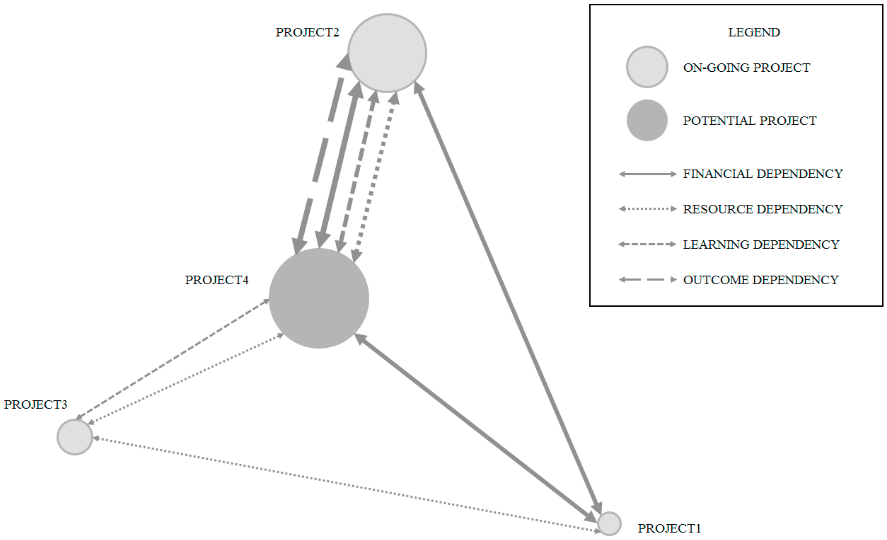

Fig. 1. Dependency map.

The overall method can be utilized for identification of critical measures in the portfolio together with reasoning between different portfolio alternatives based on different "potential projects". Thus, dependency analysis can be integrated with portfolio analysis using scenarios. Warnings can be obtained for management of each portfolio and decision support for portfolio selection can be given.

The provided example constitutes a part of a numerical case example consisting of four portfolio alternatives generated for testing of the overall portfolio management tool. After numerical testing, the method is further evaluated within the validation studies of the tool. Face validation of the model on the prototype of the tool is made by an expert review meeting consisting of four experts.

5. Conclusion

A method, which is capable of quantifying dependencies between projects, visual representation of different types of dependencies, and providing decision support on how specific dependencies could be managed has been developed. The tool developed using this method can be utilized to identify the critical dependencies between the projects within a portfolio, generation of different scenarios and evaluation of these scenarios based on various attributes including the project dependencies. It is argued that utilization of the proposed method and the tool may help development and management of successful project portfolios. The method presented in this paper may be used to measure relations between projects for different purposes such as risk assessment, resource planning, assessment of project complexity, etc.

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