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Forging a Double-Edged Sword: Resource Synergies and Dependencies in Complex IT Project Portfolios

by

Sven Radszuwill, Gilbert Fridgen

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University of Augsburg, D-86135 Augsburg
Visitors: Universitätsstr. 12, 86159 Augsburg
Phone: +49 821 598-4801 (Fax: -4899)

University of Bayreuth, D-95440 Bayreuth
Visitors: Wittelsbacherring 10, 95444 Bayreuth
Phone: +49 921 55-4710 (Fax: -844710)

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Sven Radszuwill
FIM Research Center
University of Bayreuth
Wittelsbacherring 10
95444 Bayreuth, Germany
sven.radszuwill@fim-rc.de

Gilbert Fridgen
FIM Research Center
University of Bayreuth
Wittelsbacherring 10
95444 Bayreuth, Germany
gilbert.fridgen@fim-rc.de

Abstract

These days, due to the high level of interactions between individual projects, IT project portfolios are best described as IT project networks. While varied and frequent interactions between single IT projects create additional risks, they also generate the possibility of additional synergistic effects. This, however, is not reflected in current methods for IT project portfolio evaluation and project portfolio selection, which neither account for specific network characteristics nor do they clearly distinguish between the types of interaction and their effects. In this paper, we model resource synergies and dependencies within IT project networks by means of weighted, undirected and directed graphs and describe how alpha centrality allows for an assessment of both. We further illustrate the importance of accounting for network characteristics and the equal importance of distinguishing between resource synergies and resource dependencies. Our model can therefore be applied to gain practical insights on IT project portfolios.

Keywords: IT portfolio management, project portfolio selection, project management, resource interactions, interdependency, synergy

Introduction

"Around the end of the second millennium of the common era a number of major social, technological, economic, and cultural transformations came together to give rise to a new form of society, the network society" (Castells 2010, p. 1). The characteristics of networks also surface in today's IT project portfolio management (ITPM). While the spending in Information Technology (IT) continues to rise (Gartner 2016), the increasing amount of IT projects leads to greater interconnectedness: a huge challenge today's ITPM. In step with substantial technological transformations over the last decades, large companies in particular continue to encounter challenges and opportunities to continuously enhance their IT capabilities, and likewise their IT project and project portfolio management. The success of IT projects and project portfolio management is heavily interdependent, as the success or failure of a single project can affect the entire project portfolio.

A lot of research has been conducted on project success and failure (e.g. Basten et al. 2013; Flyvbjerg and Budzier 2011; The Standish Group 2012, 2013). The varied but astonishingly high failure rates this research have revealed are predicated on the lack of risk valuation of dependencies between IT projects in particular (Buhl 2012). One project's success or failure within an IT project portfolio does not only enhance or diminish the project's isolated value, it may also have a major impact on a variety of other projects, too, which is a key property of networks. Thus, a holistic portfolio evaluation is essential as the number of projects within the portfolio and their interactions make the IT project portfolio a complex IT project network. Therefore, we use *IT project portfolio* and *IT project network* interchangeably throughout this paper and consider the (sub-) set of all IT projects of a company or business unit (including projects that have a strong connection to IT) as the IT project portfolio.

The consideration of network properties becomes even more challenging as companies encounter numerous options to add new projects (from the set of candidate projects) to their portfolio during project portfolio selection (PPS) processes. Likewise, they may also add, remove, or alter interactions within the portfolio. Thus, a distinct assessment of IT project portfolios and of (candidate) projects' interactions from a network perspective is advised for project portfolio evaluation and throughout PPS processes. However, methods used for project portfolio evaluation and the identification of interactions should be applied in a consistent manner (Bardhan and Sougstad 2004), no matter how complex and manifold the project portfolio becomes. This is a complicated task in itself, and the missing distinction of interaction types makes it even more difficult. Together, these circumstances increase the chances that a project's impact to the overall IT project portfolio will be falsely estimated.

Unsurprisingly, interactions between IT projects have received increasing attention. Since denominations in literature are inconsistent in this context, we want to establish an unambiguous wording and follow Eilat et al. (2006) and Kundisch and Meier (2011b) in using the term *interaction* (instead of *interdependency)* as an umbrella term. Particularly, we do not use the terms interaction and (inter)dependency interchangeably. As resources, in particular, are usually scarce, *resource interactions* are of "high relevance for IT/IS project portfolio selection" (Kundisch and Meier 2011a). For example, the potential savings due to shared resources must be compared with the potential damage bound resources might cause to a project in case of a preceding project's delay or cost-overrun. In general, resource interactions may enable additional projects or lead to a portfolio with higher benefits (Meier et al. 2016) although they may lead to unintended negative effects. As a clear distinction in this regard is missing in the current literature, we distinguish between *resource synergies* (interactions causing positive effects) and *resource dependencies* (interactions causing negative effects) and subsume them under *resource interactions*. Though resource interactions seem to be addressed quite frequently in the literature (Müller et al. 2015), adequate techniques for a detailed assessment are missing (Meier et al. 2016).

Furthermore, (resource) interactions between IT projects might not only affect directly connected projects (project 2 is connected to project 1) but even projects that are transitively connected to each other (project 3 is connected to project 1 which is connected to project 2). However, to the best of our knowledge, transitive (or higher-order) interactions and their intensity are not adequately accounted for by prevailing IT project portfolio and PPS approaches, although the representation of higher-order interactions is required for realistic IT modeling (Graves et al. 2003).

This being said, IT project portfolio evaluation and an integration of candidate IT projects in existing IT project networks – particularly regarding resource synergies and dependencies – promises to facilitate improved PPS decisions. The question of how candidate projects alter resource interactions and integrate in existing portfolios can be approached by providing a ranking of the portfolio's projects. To address the gaps in the research as outlined above, we employ the following research question:

How can (candidate) IT projects be ranked considering both resource synergies and dependencies with regard to the specific IT project network characteristics?

To answer this research question, we follow the research cycle of Meredith et al. (1989), who divide research activities into stages of description, explanation and testing. These stages are rarely as distinct in practice as they are in theory, and can rather be regarded as an ongoing process of research activities (Meredith et al. 1989). The contribution of this paper is placed in the explanation and testing phase and structured as follows.

As description "must precede explanation and testing" (Meredith et al. 1989, p. 302), we describe how to model IT project networks using graph theory, and depict the current state of research on interactions in the field of ITPM. We outline research regarding different types of interactions, their properties and classification approaches, as well as evaluation methods in the context of ITPM and relevant related research areas. Subsequently, we focus on the consideration of resource interactions and the distinction of synergies and dependencies in particular. As for the explanation stage and main contribution of this paper, we extend the current state of research by refining the modelling procedure for resource synergies and dependencies, incorporating their specific properties. Thereby, we propose a resource synergy graph (RSG) and a resource dependency graph (RDG) for IT project networks. As initially outlined by Wolf (2015), we use alpha centrality as a suitable measure for IT project portfolios containing interactions, and extend and analyze applicability. We present an application example to rank IT projects with regard to resource synergies and dependencies, and illustrate how to use alpha centrality. We then demonstrate comparability of the results and how the results for both kinds of resource interactions may be interpreted. Furthermore, we conduct a simulation based analysis, which is one major mode of testing (Meredith et al. 1989), and derive insights into the parameters' impact on the ranking results. Last, we summarize, conclude, and reveal limitations and future research directions.

Theoretical Background

Information Systems and project management literature contains a variety of methods for (IT) project portfolio selection and evaluation. Yet the challenge of dealing with increasingly complex circumstances makes the need to address the network characteristics of today's IT project portfolios obvious. To account for the current state of research in ITPM (description stage), as a starting point, we outline the concept of modelling IT project networks using graph theory. To depict the interaction characteristics in IT project portfolios, we give an overview outlining types of, and classification approaches to, interactions, before focusing on resource interactions in particular. We outline IT project synergy and dependency consideration before introducing a distinction between resource synergies and dependencies. Regarding quantitative methods for IT project portfolio evaluation and selection, we proceed analogously, yet we refer to further literature where applicable in order to not exceed the scope of this paper.

Modeling IT Project Networks Using Weighted Graphs

We follow Wolf (2015) and Beer et al. (2015) in regarding IT project portfolios as IT project networks. In basic terms, we model the entire network depicting projects by nodes and interactions by edges. An edge between node 1 (project 1) and node 2 (project 2) depicts a relation between these two nodes (projects). In Figure 1, we illustrate a simple IT project network modeled by a simple, directed graph. Here, project 1 and 3 directly impact project 2, and project 3 directly impacts project 2. In other words, project 2 depends on project 1 and 3. Importantly, project 3 also impacts project 2 over the transitive interaction with project 1. A second important factor is the strength of interaction, written as weight $w_{i,j}$ next to the respective edge. A value $w_{i,j} > 0$ implies that an edge points from node i to node j. We model interactions so that a value of 0.2 represents a weaker impact than a value of 0.5. Weights $w_{i,j}$ are usually from the bounded interval $[0,1]$. A weight of 0 means that there is no edge. To apply network algorithms, the adjacency matrix $\boldsymbol{A}$ contains the network relations, i.e. $a_{i,j} > 0$ in case an edge points from node i to node j, thus $a_{i,j} = w_{i,j}$ for weighted graphs.

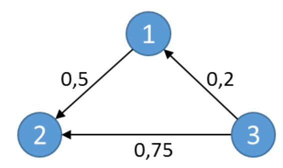


Figure 1. IT project network consisting of three projects modeled using a directed, weighted graph

We assume that an estimation of the weights $w_{i,j}$ can be achieved using established methods, e.g. expert judgement. However, the appropriate identification and estimation procedure of interactions in IT project portfolios is beyond the scope of this paper and provides room for further research.

Facing Resource Interactions in IT Project Portfolios

A classification of interactions and a differentiation from other types of interactions is mandatory to account for the specific characteristics of resource interactions. Thus, we provide an overview on the current state of classifications for interactions between IT projects in a portfolio context before we elaborate on resource interactions in particular.

There are various attempts to classify interactions in IT project portfolios in literature. Beer et al. (2015) found that "some articles just mention certain kinds" of interactions while others provide classification. Oftentimes a distinction between "resource dependencies, technical dependencies or dependencies regarding benefits" (Beer et al. 2015, p. 710) is made (Lee and Kim 2001; Santhanam and Kyparisis 1996; Tillquist et al. 2002; Zuluaga et al. 2007). A well-established way to structure dependencies is provided by Wehrmann et al. (2006). Firstly, they divide dependencies into *inter-* and *intratemporal dependencies*. *Intertemporal dependencies* depict relations between projects over a period of time, whereas *intratemporal dependencies* are defined in one point or period in time. Secondly, they further divide *intertemporal dependencies* into *technical* and *logical dependencies*. *Intratemporal dependencies* comprise *resource dependencies* (*technical* or *personnel*) and *structural dependencies* (*process dependencies, data dependencies* or *functional dependencies*) (Beer et al. 2015). Drawing on Diepold and Dzienziol (2009) and Kundisch and Meier (2011b), Müller et al. (2015) provide another subclassification as they divide *intertemporal interactions* into *output* and *output-resource interactions*, and *intratemporal interactions* into *resource, output* and *output-resource interactions*. Hereby, they define *output interactions* as those which "occur if there is a non-proportional decrease or increase in the benefits achieved when two or more projects are conducted together rather than individually" (Müller et al. 2015, p. 739). *Resource interactions* occur in cases where the required amount of resource for joint implementation differs from the sum of individual implementation (Müller et al. 2015). Thereby, *resource interactions* are only intratemporal, whereas *output-resource interactions* (where the output of one project is the mandatory resource of another project) can be both, intra- and intertemporal (Müller et al. 2015).

Classification of Resource Interactions

To model resource synergies and resource dependencies appropriately, we draw on the specific characteristics of resource interactions. We define *resource synergies* as resource interactions that can have positive effects on the project portfolio in terms of portfolio costs or value, *resource dependencies* as resource interactions that can have negative effects on the project portfolio in terms of portfolio risk. We assign the prevailing definitions of resource interaction types from the literature to our definition of synergies or dependencies (Figure 2), based on the authors' definition. In cases where these definitions do not contain a clear distinction in this regard, or where they address both (synergies and dependencies), we assign these interaction types to both synergies and dependencies. Notwithstanding ambiguous definitions, a distinction can be reasonably applied, which we outline in the following.

Resource interactions are commonly understood to result from the sharing of scarce resources, i.e. sharing either personnel resources or hard- or software (technical resources) (Beer et al. 2015). In the field of

Information Systems in particular, this sharing is natural as it accounts for a substantial amount of cost savings (Santhanam and Kyparisis 1996). Resource interactions have been explored, particularly in the case of IT projects (Bardhan and Sougstad 2004; Kundisch and Meier 2011a, 2011b; Lee and Kim 2001; Santhanam and Kyparisis 1996) and R&D projects (Aaker and Tyebjee 1978; Eilat et al. 2006; Fox et al. 1984; Gear and Cowie 1980; Maio et al. 1994). The definition of resource interactions in this literature varies slightly but basically states that the sum of shared resources differs (usually decreases) if projects are conducted conjointly rather than separately. It is important to note that "resource interactions affect both expected costs and risk of the overall project portfolio" (Heinrich et al. 2014, p. 9), as the latter is frequently neglected in the literature. Though being diversely classified, resource interactions are commonly regarded as intratemporal and not intertemporal (Müller et al. 2015; Wehrmann et al. 2006). Kundisch and Meier (2011a) provide a more distinct classification and speak of *allocation interactions*, *performance interactions,* and *sourcing interactions*. They define the three categories as follows:

- *Allocation interactions* are apparent, if "the sum of the required resource units for a set of projects that share this resource is less than the sum of the resource units required if the projects had been considered independently" (Kundisch and Meier 2011a, p. 7).
- *Performance interactions* are apparent if a personnel resource working in two (or more) projects is more productive then in a single project, e.g. due to learning effects. Besides, Kundisch and Meier (2011a) state, that they imply positive and negative effects when referring to performance interactions.
- *Sourcing interactions* "occur when the average price – or cost rate – per resource unit is not constant for varying quantities" (Kundisch and Meier 2011a, p. 8), i.e. this may apply for personnel as well as for non-personnel resources.

Although Kundisch and Meier (2011a) mainly explore the synergistic effects of resource interactions, they do not in each case clearly distinguish synergies and dependencies. Thus, from the definitions stated above, we classify allocation and sourcing interactions as synergies, and performance interactions as synergies and dependencies (cf. Figure 2). We also note a distinction between *personnel* and *non-personnel resources*.

By contrast, Kundisch and Meier (2011b) divide *resource-resource interactions* into *competitive* and *complimentary resource utilization interactions,* characterized by the amount of resources required for the joint implementation being greater (less) "than the sum of the resources required if the projects would have been implemented separately" (Kundisch and Meier 2011b, p. 482). Consequently, we classify them as dependency (first) and synergy (second) (Figure 2). Both relations are regarded as symmetric (two projects influencing each other) and the effects of the interactions are noted as cost increase (first) and decrease (second) (Kundisch and Meier 2011b). Kundisch and Meier regard *output-resource interactions* as being apparent if an influenced project needs the output of the influencing project as resource (input). This type of interaction is important to mention because it reveals very clearly that resource interactions can be asymmetric under certain conditions. Kundisch and Meier (2011b) subdivide *output-resource interactions* as follows:

- *Binary contingency interaction:* It may be that the influenced project "cannot stand alone" (Kundisch and Meier 2011b, p. 483) as it needs the output of other projects.
- *Continuous competitive contingency interaction:* The influenced project "may stand alone, but the outputs of related projects deteriorate the resource requirements/utilization of the influenced project" (Kundisch and Meier 2011b, p. 483).
- *Continuous complementary contingency interaction:* When the output of other projects improves the resource requirements of the influenced project (Kundisch and Meier 2011b).

Hereby, we classify the first type as dependency, the second type as dependency as it causes a cost increase, and the third type as synergy (cf. Figure 2) as it causes a cost decrease (Kundisch and Meier 2011b). Moreover, Kundisch and Meier (2011b) declare all these relations as asymmetric, i.e. one project is influenced by the other.

As an important interim conclusion, we state that:

(1) Resource sharing is understood as a symmetric relation whereas one project influencing the other is regarded as an asymmetric relation.
(2) A clear distinction between resource synergies and resource dependencies is missing, although positive and negative interaction effects are oftentimes mentioned.
(3) For most classifications of resource interactions, a distinction between personnel and non-personnel (technical) resources is present or can be reasonably applied.

In the following, we make use of the outlined classifications to describe an allocation of resource types and interaction types (Figure 2) and derive a classification of symmetric/asymmetric relations. This allocation serves as basis for our modelling procedure as it justifies the general applicability for the prevailing resource types in the literature. Since the existing literature on (resource) interactions only sometimes mentions the double-edged nature of resource interactions (2), we forge a distinction between synergies and dependencies in the following. However, a consistent notion in this literature is that resources can be divided into personnel and non-personnel resources (3).

The Concept of Synergy between IT Projects

As previously mentioned, the term (inter)dependency is oftentimes used interchangeably with the term interaction. This implies that an additional review on the current state of research in terms of dependencies would be redundant as it is included in the preceding sections on interactions. For resources, however, the concept of synergy must be outlined to allow for a clear distinction to be made. Literature on management strategy in general defines *synergies* (or the synonymously used *economies of scope*) among businesses to refer to situations in which the joint value of a business is greater than their aggregated individual values (Tanriverdi and Venkatraman 2005). According to Cho and Shaw (2009, p. 4), "IT synergy refers to additional return that a firm can achieve from multiple IT investment units, which cannot be obtained from stand-alone individual units". Due to their characteristics, IT resources entail a particularly great possibility of enhancing synergy, as they can be used remotely, by multiple users, and enable the sharing of processes and data (Cho and Shaw 2009).

Two types of IT synergies have been addressed in the literature: *subadditive cost synergies* and *superadditive value synergies* (Cho and Shaw 2013; Tanriverdi 2006; Tanriverdi and Venkatraman 2005). Tanriverdi (2005) firstly defines superadditive value or subadditive costs for business units as the main types of synergies, before moving on to discuss the concept for IT resources. For two units a and b, the joint value is superadditive, if $\mathrm{Value}\,(a,b) > \mathrm{Value}\,(a) + \mathrm{Value}\,(b)$, and costs are subadditive, if $\mathrm{Cost}\,(a,b) < \mathrm{Cost}\,(a) + \mathrm{Cost}\,(b)$ (Tanriverdi and Venkatraman 2005). According to Cho and Shaw (2009), subadditive cost synergy arises from shared inputs, e.g. shared resources. Superadditive value synergy is derived from the notion of complementarity (Cho and Shaw 2009), that is "doing (more of) any one [...] increases the returns [...] of the others" (Milgrom and Roberts 1995, p. 181).

In order to apply these concepts to IT project portfolios, we have formulated the following definitions:

- *Subadditive IT project cost synergy:* When the sharing of resources between two or more projects leads to lower costs compared to conducting the projects individually.
- *Superadditive IT project value synergy:* When the sharing of resources between two or more projects leads to increased value compared to conducting the projects individually.

Incorporating these definitions of synergy into our classification of resource types and interaction types (Figure 2) we provide an integrated matrix classification of all relevant resource and resource interaction types. In doing so, we present a generally applicable modelling procedure for resource interactions.

A Distinction between Resource Synergies and Resource Dependencies

In this section, we make clear the case for refining current definitions of resource interactions, which can be further categorized as either resource synergies or resource dependencies. Further, we highlight the difference between resource interactions and effects of resource interactions, which we outline in the next section.

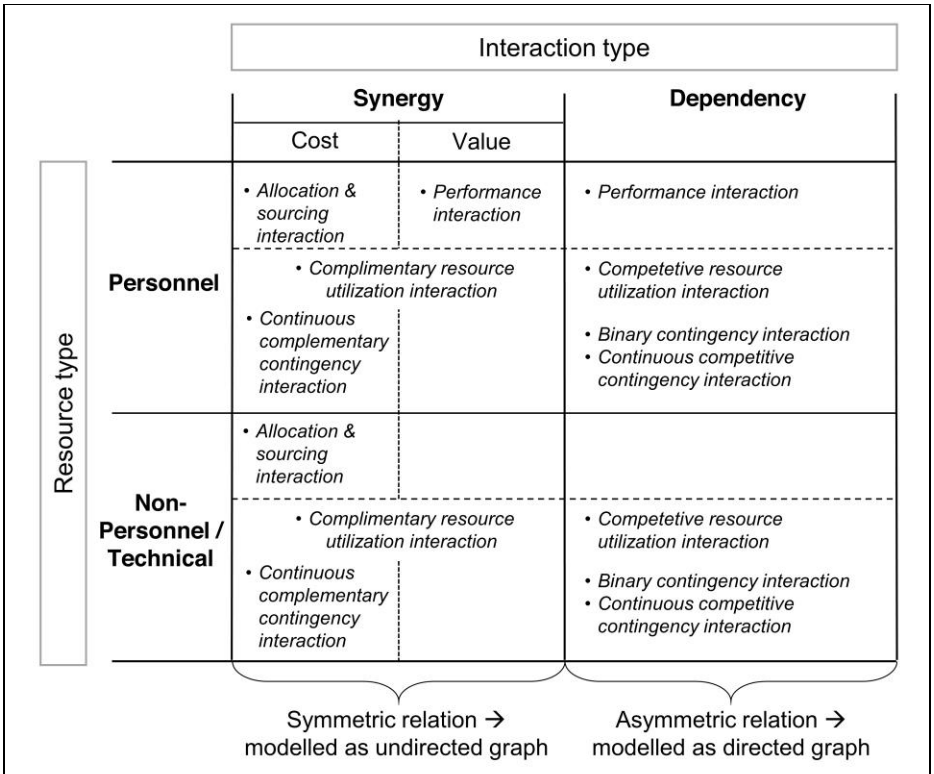


Figure 2. Distinction between resource synergies and dependencies and a classification as symmetric and asymmetric relation

The previous sections have examined resource interaction types. In Figure 2, we summarize our classification, depict each interaction type as *personnel* or *non-personnel (technical) resource,* and assign it to *(cost and value) synergy* or *dependency*. In keeping with this classification, we denote synergies as a symmetric type of relation, whereas as opposed to dependencies, which are an asymmetric type of relation. As the synergies (usually) have a positive effect on more than one project, synergies cannot be reasonably assigned to one of the interacting projects, but must instead be assigned to all of them, or to the project portfolio in question. Conversely, dependencies imply that one project directly influences the other, thus are asymmetric relations.

In this context, we want to revisit in more detail two definitions of resource interactions, as the authors' definition differs from our classification of these relations as symmetric/asymmetric. Firstly, continuous complimentary contingency interaction is subsumed under output-resource interactions, which are defined as inherently asymmetric (Kundisch and Meier 2011b). Nonetheless, since the effect is a positive one (cost decrease (Kundisch and Meier 2011b)), we classify continuous complimentary resource interactions as synergy, i.e. as a symmetric type of relation. Secondly, Kundisch and Meier (2011b) define competitive resource utilization interaction as symmetric because this interaction "affects all related projects in some way" (Kundisch and Meier 2011b, p. 482). This interaction type leads to increased resource requirements compared to the individual implementation of two projects (Kundisch and Meier 2011b), which we define as dependency, and thus as asymmetric.

Based on this classification (Figure 2) we model synergies using undirected, weighted graphs, and dependencies using directed, weighted graphs. This allows us to analyze IT project portfolios from a two-sided, interaction-focused network perspective, and provides insights as to the effects of resource interactions on other projects and on the IT project portfolio.

Synergies and Dependencies as a Key Factor in Portfolio Value and Risk

In order to ensure that assessments are rigorous, it is vital to distinguish *resource interactions* (which make up the network character) from the *effects of resource interactions* (which alter the portfolio value or risk). This is an important distinction, as what we offer here is a novel approach to the analysis of IT project networks in terms of resource interactions, which marks the first step of research in this direction. We do not quantify their impact to the portfolio in terms of (monetary) value or risk. Nonetheless, an awareness that existing (or potential) interactions can affect the value and risk of an IT project portfolio is of central importance. This being said we follow Heinrich et al. (2014) who provide an idea of *expected isolated portfolio costs* and *isolated portfolio risk* which we extend to *isolated portfolio value* and *isolated portfolio risk*, i.e. the sum of all isolated project values and the sum of all isolated project risks. As we allow isolated project value to be positive as well as negative, we cover costs within the value term. To define isolated portfolio value and isolated portfolio risk we make

Assumption 1: Each project in the portfolio possesses its own *isolated project value* and its own *isolated project risk* that it contributes if conducted in isolation, i.e. when adding no resource interactions to the portfolio.

This implies that isolated project value and risk contain neither effects of synergy nor portfolio risks due to dependencies. In other words, if this fully individual project succeeds, it delivers exactly its inherent value; if it fails, the only effect on the portfolio is that the project's inherent value is not delivered. The fact that fully individual IT projects are a largely theoretical concept serves to emphasize the need to examine interactions in IT project networks. Having defined isolated project value and risk, we assign the effects of resource synergies and dependencies to *interactive portfolio value* and *interactive portfolio risk*. As a consequence of resource synergies, the interactive portfolio value may be even greater than the isolated portfolio value itself. The same holds true for the effects of dependencies on portfolio risk. Thanks to their transitive nature, the interactive portfolio risk may easily surpass the isolated portfolio risk (and value), which is certainly not an effect intended by portfolio management.

ITPM Methods – The Status Quo of IT Portfolio Evaluation

Various approaches quantitatively address IT PPS and IT project portfolio evaluation in general. Here, we give an overview and subsequently emphasize approaches that specifically address (resource) interactions within IT project portfolios in general, and from a network perspective in particular. For a detailed outline of the development of portfolio management in connection with information technology, we refer to Reyck et al. (2005) who provide a historic as well as thematic overview.

Beer et al. (2015) argue that IT portfolio evaluation and IT project evaluation methods cannot be seen as individual since, at least to some extent, IT portfolio evaluation usually comprises IT project evaluation. Many approaches to quantitative IT project or portfolio evaluation (Beer et al. 2013; Beer et al. 2015; Fridgen and Müller 2011; Marchewka and Keil 1995; Wehrmann et al. 2006) are based upon Markowitz' Portfolio Theory (Markowitz 1952). The foundational strategy in these approaches is to proportion the expected value μ and a risk term σ to obtain an optimal portfolio, i.e. the portfolio with the highest expected return. Algorithms based on Markowitz (1952) oftentimes use a correlation or a covariance matrix to depict dependencies between projects (Beer et al. 2013; Fridgen and Müller 2011). Other quantitative methods like linear programming (Ghasemzadeh and Archer 2000), goal programming (Lee and Kim 2001), or real options approaches for IT PPS (Bardhan and Sougstad 2004; Benaroch 2002; Schwartz and Zozaya-Gorostiza 2003) have been developed but largely neglect the specific characteristics (e.g. interactions) of IT project portfolios (Ullrich 2013). Aaker and Tyebjee (1978) present a model for R&D project selection and incorporate resource utilization, technical interdependencies and effect interdependencies (Aaker and Tyebjee 1978) in their optimization model. Kundisch and Meier (2011a) engage an optimization model to develop an optimal portfolio that accounts for their aforementioned types of resource interactions. They account for positive and negative effects of resource interactions where applicable. Meier et al. (2016) address the question of how the identification and evaluation of resource interactions can be adequately supported. They provide an optimization model to develop an optimal project portfolio that allows for the integration of resource interactions between all projects. The model accounts for the effects of resource interactions which can "either be cannibalizing or synergistic" (Meier et al. 2016, p. 86).

Except for those offered by Beer et al. (2015) and Wolf (2015), almost none of these approaches examines IT project portfolios from a specific network perspective. Based on IT project portfolios modeled as graphs, Beer et al. (2015) address different kinds of dependencies between projects by integrating alpha centrality into their method in order to quantify systemic risk in IT project portfolios. Beer et al. (2015) provide an overview of the applicability of various centrality measures used to address the criticality of IT projects within an IT project portfolio based on predefined criteria.

Synergies in general are rarely addressed in IT PPS literature. Following Kroll et al. (1984), Cho and Shaw (2009) apply Markowitz's efficient frontier to IT synergy effects and conclude that firms with a high risk tolerance may particularly benefit from IT synergy enhancement within their portfolio. Similar to the work of Benaroch (2002), Bardhan and Sougstad (2004) develop a nested real options approach to IT investment decisions, taking the benefits and costs of a portfolio of 31 projects into account. They specifically consider the enabling aspects of IT projects to subsequent projects - synergies, in our phrasing - but do not address the limiting aspects of dependencies. Pendharkar (2014) draws on the real options model of Pendharkar (2010) and provides a decision-making framework which includes both synergies and dependencies. The optimization model put forward by Meier et al. (2016) offers users the opportunity to define each resource interaction between two projects as cannibalizing or synergistic. One limitation of these models, however, is that they do not consider effects such as transitive interactions which may result from the network structure.

Despite these relatively far-reaching approaches, an adequate assessment of resource interactions incorporating network structures and their characteristic properties is still missing. Crucially, approaches that consider, distinguish, and depict resource synergies as well as resource dependencies in a network context do not exist.

A new Model for Incorporating Resource Interactions

A Resource Synergy Graph and a Resource Dependency Graph

We model resource synergies and dependencies using two separate graphs. We classify resource synergy as a symmetric relation and resource dependency as an asymmetric relation. On this basis, we now use an undirected graph to model resource synergy and a directed graph to model resource dependency, as illustrated in Figure 3. We will refer to these as a *resource synergy graph (RSG)* and *resource dependency graph (RDG)* from now on.

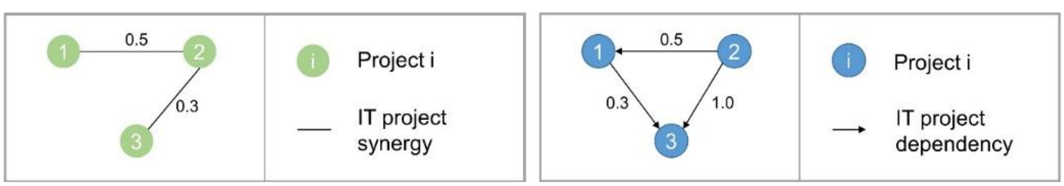


Figure 3. Resource synergies modeled by an undirected graph (left) and resource dependencies modeled by a directed graph (right)

For simplicity, we depict an IT project portfolio containing only three projects. For the RDG we determine that an edge pointing from node (project) i to node (project) j represents that node (project) j depends on node (project) i. For the RSG, this applies differently, as it is by definition undirected, i.e. interacting projects influence each other. Note that dependencies between two projects can also exist simultaneously in both directions, which we model using two directed edges. In this small illustration, project 1 has resource synergy with project 2 and depends on project 2. Moreover, project 3 depends on both project 1 and project 2, but only project 3 has a synergy with project 2. Furthermore, there is a transitive dependency: project 3 depends on project 1 and project 1 depends on project 2, thus, project 3 transitively depends on project 2 as well (in addition to the direct dependency). As is the standard procedure for weighted graphs, we assign weights from the bounded interval [0,1] to each edge. The question of how to identify and quantify the intensity (weights) of (resource) interactions is important to address and leaves room for further research.

Ranking IT Projects using Alpha Centrality

Having their foundation in graph theory, approaches from the area of social network analysis can be used to analyze patterns in networks (Kim et al. 2011), and network perspectives are becoming a "lingua franca across virtually all of the sciences from anthropology to physics" (Borgatti and Li 2009, p. 5). One approach to the analysis of such networks is the use of centrality measures, which are designed to identify the most central node within a network, depending on different input parameters. Wolf (2015) analyzes the applicability of centrality measures to assess the criticality of IT projects in IT project portfolios, i.e. to identify and rank projects that are critical to the portfolio, based on their dependencies in general. Another method that must be mentioned is provided by Meier et al. (2016) and incorporates resource interactions on a detailed level for specific resources and specific projects. It enables users to rank influential resource interactions "according to their potential impact on the benefit of the portfolio" (Meier et al. 2016, p. 89) but does not address the network character of IT project portfolios.

Based on five requirements essential to IT project portfolios, Wolf (2015) concludes that alpha centrality is a suitable approach to identifying the most critical project in such a context and when evaluating the network from a dependency perspective. According to Wolf (2015), an appropriate quantitative measure must account for:

(1) directed relations between projects,
(2) the strength of dependencies,
(3) the number of directly dependent projects,
(4) the number of indirectly dependent projects and
(5) the importance of directly and indirectly dependent projects (Wolf 2015).

By assessing the IT project network from both a resource synergy perspective and a resource dependency perspective, we provide a holistic view of the entire IT project network and its components. Since we model synergies using undirected, weighted graphs, an appropriate measure must also be applicable under this circumstances. Indeed, alpha centrality can be applied to undirected, weighted graphs as, in this case, alpha centrality converges to the standard eigenvector centrality (Bonacich and Lloyd 2001). In both cases (symmetric and asymmetric), we assume that there is a largest eigenvector $\lambda_{max}(\boldsymbol{A})$ of the adjacency matrix $\boldsymbol{A}$, which is almost always the case for any real data (Bonacich and Lloyd 2001). This makes alpha centrality an appropriate approach to account for both synergies and dependencies based on our modelling procedure. Additionally, a quantitative assessment based on the same measure has the major advantage of making the results comparable.

Bonacich and Lloyd (2001) first offered alpha centrality as an alternative or an extension to eigenvector centrality, similar to the so called Katz centrality (Katz 1953). Defined by

$$x = (\boldsymbol{I} - \alpha \boldsymbol{A}^{\boldsymbol{T}})^{-1} e,$$

where $\alpha \in \mathbb{R};\ x, e \in \mathbb{R}^n; I, A \in \mathbb{R}^{n \times n}$, alpha centrality assigns a centrality score x_i $(i = 1, \dots, n)$ to each node i within the network, thus, to each project. $\boldsymbol{I}$ represents the identity matrix, $\boldsymbol{A}^{\boldsymbol{T}}$ is the transpose of the adjacency matrix. The vector e can be regarded as a vector of exogenous sources and accounts for information independent of the network (Bonacich and Lloyd 2001), e.g. the project budget (Wolf 2015). As our main concern is the network structure, i.e. the endogenous status, we follow Bonacich and Lloyd (2001) and Wolf (2015) and initially set $e = (1, \dots 1)^T$. The value of α balances endogenous and exogenous influences and can be chosen from $]0, \lambda_{max}(\boldsymbol{A})^{-1}[$, where $\lambda_{max}(\boldsymbol{A})$ is the principal eigenvalue of $\boldsymbol{A}$. In general, the greater the value of α, the greater the influence of the network. Thus, it is advisable to select an α value close to the upper boundary (if intended) to account for the network structure in particular. That said, a close analysis on the choice of alpha is dependent on the network structure and beyond the scope of this paper.

We regard resource dependencies and synergies individually which also implies that we compute two centrality vectors, one for the RSG, one for the RDG. With that we obtain two project rankings which allow us to compare the results. To provide better comparability, we normalize the resulting vector x of centrality scores using the standard euclidean norm.

Application Example

The Impact of Resource Synergies and Resource Dependencies

To explain how alpha centrality can be used to rank projects analyzing resource synergies and dependencies, we provide an example of its application. As we cannot draw on real-world data yet, we evaluate a realistic but hypothetical IT project portfolio. We face a familiar situation for scientists (and practitioners) here. As long as there is no approach to the analysis of specific data - in this case, the analysis of resource interactions - there is no incentive for practitioners to gather this data. Vice versa, for researchers it is particularly hard to incentivize the collection of such data when the benefits of a new approach are not yet clear. This is why we provide an example of the application of our model as a first step of research. This approach also has the major advantage of enabling us to simulate various scenarios.

Our initial project portfolio consists of nine projects and various resource interactions. To this network, we add an exemplary candidate IT project (project 10) and explain how the derived insights can support the PPS process. To reveal implications of the network structure and of the chosen method, we compute centrality scores for this example for a predefined range of the parameter α.

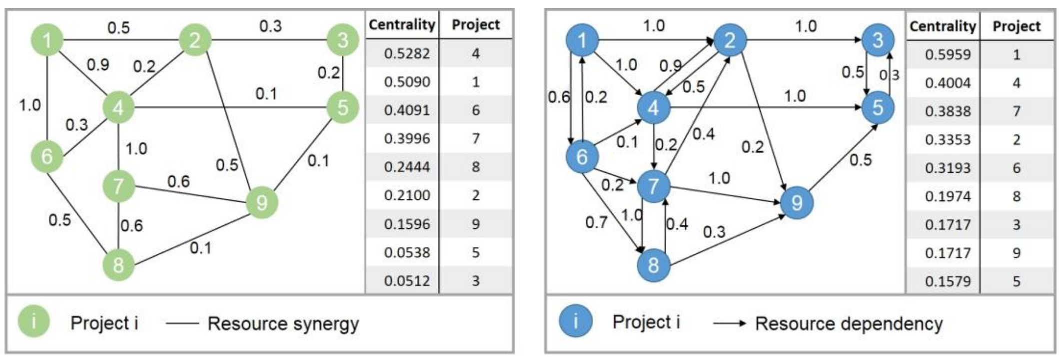


Figure 4. RSG (left) and RDG (right) for a network of nine projects and the respective centrality scores of each project

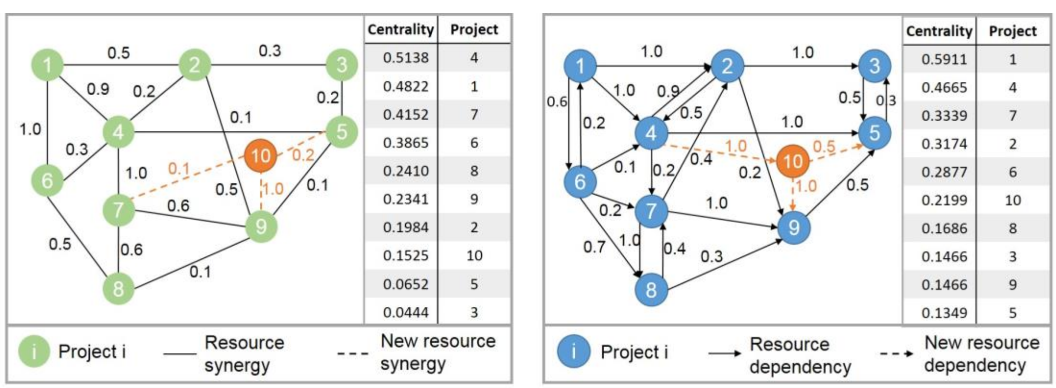
We depict our exemplary portfolio of nine projects in Figure 4, displaying the RSG and RDG separately. Regarding the general setup of resource interactions in this project network, we deliberately use a structure that is similar for synergies and dependencies in some parts of the network (i.e. for some projects), but differs in others. With this setup, we are able to illustrate different effects of to the network structure. For example, we model projects 2 and 7 to have no synergy but project 2 to depend on project 7. Further, we use an IT project network that contains both projects with many interactions (e.g. project 4) and projects with few interactions (e.g. project 3). For example, in the RSG, project 4 can be considered as a project that has synergies with many different projects. The synergies to project 1 and 7 have a high intensity: one might think of a comparatively expensive technical resource that can be shared. However, in the RDG it surfaces that project 4 also has a high dependency on project 1. Imagine that project 4 cannot use a resource as long as the same resource is being used by project 1. From this perspective, the interactions between project 1 and 4 may have strong positive as well as negative effects. By contrast, project 7's dependency on project 4 is of low intensity compared to the high intensity of synergy. These types of relationships can be observed at different points in the network.

We compute alpha centrality using the input parameter displayed in Figure 4. For our initial illustration we set $\alpha = 0.5$ for both graphs. Further, we normalize the centrality scores to allow for better comparability. As outlined in the previous section, we can choose $\alpha \in]0; 0.519[$ for the RSG ($\lambda_{max}(A) \approx 1.928$) and $\alpha \in]0; 1.405[$ for the RDG ($\lambda_{max}(A) \approx 0.712$). This implies that, for the RSG, the value of α is already close to its upper boundary, i.e. the endogenous effects (due to network structure) are the most significant. In contrast, for the RDG this is not the case. Consequently, the effects of the network structure can be given more weight by a higher value of α. We analyze the behavior for different values of α in the next section.

We obtain centrality rankings as displayed in Figure 4. It turns out that project 4 and 1 are the most central in terms of resource synergies. Project 1 is also by far the most central with regard to resource dependencies, followed by project 4. This might seem initially seem surprising as we display project 1 rather peripherally in the graph. And while three projects are directly dependent on project 1, there are also three projects that depend on projects 4, 6 and 7 with evenly high intensities. Here, the notion of transitivity comes into play. When we compare project 1 and project 7, which have a similar amount and intensity of direct dependencies, it becomes evident that the projects depending on project 1 have many projects which depend on them in turn. Alpha centrality takes this kind of network structure (a kind of chain-linking) into account and, as a result, project 1 is considered more central than project 7. At the end of both rankings we find the projects 9, 5, and 3. However, for the RSG project 3 is by far the least central, whereas it has the same centrality score as project 9 for the RDG. Similar observations can be made with regard to the other projects in the ranking.

Even before including information on new candidate projects, a distinction between resource synergies and dependencies is generally valuable from a portfolio management perspective. From the two rankings provided, we can draw diverse conclusions. There is at least one project (project 1) that requires close attention as many other projects (transitively) depend on it. It also has a substantial amount of resource synergies within the portfolio. On the other hand, there are projects that have only minor resource synergies and dependencies (e.g. 3, 5, and 9), and thus are less important from a network perspective. There are also projects (e.g. project 2) that come with low resource synergy scores but comparatively high resource dependency scores and thus might benefit from resource re-allocation.

To emphasize the ways in which further insights such a ranking can enhance the PPS process, we add another project (candidate project) to the existing network. One can imagine a situation where a choice must be made between three similar projects that all require different resources and hence add different resource interactions to the portfolio. We expect our candidate project 10 to have resource synergies with projects 5, 7, and 9 and resource dependencies with projects 4, 5, and 9. To address the question of how this candidate project would alter our portfolio from a resource interaction perspective, we compute new centrality scores, depicted in Figure 5. Note that the centrality scores of Figure 4 and Figure 5 themselves cannot be reasonably compared to one another as we normalize the values.



Centrality	Project
0.5138	4
0.4822	1
0.4152	7
0.3865	6
0.2410	8
0.2341	9
0.1984	2
0.1525	10
0.0652	5
0.0444	3

Centrality	Project
0.5911	1
0.4665	4
0.3339	7
0.3174	2
0.2877	6
0.2199	10
0.1686	8
0.1466	3
0.1466	9
0.1349	5

Figure 5. RSG (left) and RDG (right) including the new candidate project with assigned centrality scores

It turns out that, based on the assumed interactions and intensities (weights), project 10 adds more dependency to our resource interaction network than it adds synergy. All other things being equal, if it is possible to do so it may be advisable to choose another candidate project with a higher synergy or lower dependency ranking. However, the effects are not straight-forward but rather complex and manifold. It may be that a candidate project also directly alters existing interactions or their intensities when, for example, it is placed directly between two other projects (in terms of interactions). To ensure the examples we provide are clear and comprehensible, we do not model this case here. Yet, another similar effect can be observed: by adding project 10 to our network, the ranking of existing projects in terms of synergies has been changed. Though the intensity of the synergy between project 7 and 10 is rather low, project 7 is now ranked higher than project 6. Similar effects can be observed, for example, in the case of projects 2 and 9. So although our new project 10 is more central in terms of dependencies, the ranking of other projects does not change. Note that the centrality scores do so nonetheless. For example, the centrality score of project 4 increases as one more project now depends on it. This is surprising as it means that adding a candidate project to an existing portfolio does not only alter interactions, but may also alter the relative impact all projects have on each other, even though these projects are not necessarily (directly) connected.

The Effects of Resource Interactions due to the Network Structure

The ranking derived, unsurprisingly, depends on the choice of the input parameter α. To provide deeper insight to the effects of the network structure, we analyze our application example for the complete range of α, i.e. for the RSG we choose $\alpha \in]0; 0.519[$ and for the RDG we choose $\alpha \in]0; 1.405[$. For both graphs we compute the ranking for 100 evenly distributed values of α within the respective interval.

We use the complete IT project network, including our candidate project 10 and the weights depicted in Figure 5, and visualize the normalized centrality scores for each project.

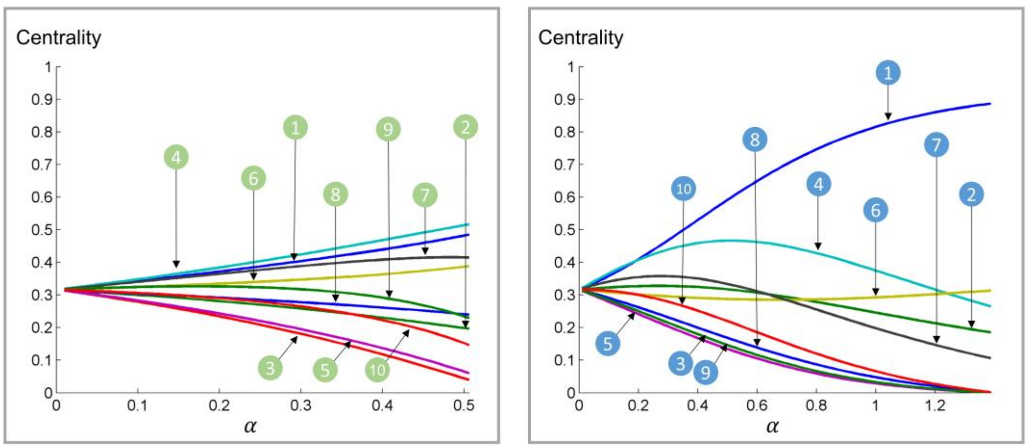


Figure 6. Centrality Scores for the RSG (left) and RDG (right) for the complete range of α

It is apparent that the higher the value of α, the more distinguishable the centrality scores for both graphs become. This is to be expected as α balances the relative importance of endogenous effects versus exogenous status (such as project budget) contributed by the vector e. Note again that we set $e = (1, \dots 1)^T$ as we are primarily interested in the effects of the network structure. A high value of α yields a high impact of the network structure on centrality scores.

Of further note here is the fact that centrality scores for the RDG are more distinguishable than for the RSG. From an algorithm perspective, this result is to be expected as we modeled the RSG using an undirected, weighted graph. Yet because we did this for a well-established contextual reason, it is insightful for ITPM and PPS processes. From a risk perspective, this implies that adding candidate projects which have strong resource interactions is more likely to increase the risk to a project portfolio. Imagine a project that is undertaken for the reason that "it can be easily implemented on top of our current projects with the resources at hand". Perhaps this particular project prohibits the success of other projects precisely because it binds scarce resources. Accordingly, our method can reveal that it may not be worth taking such a risk. However, as symmetric relations, synergies cannot only be assigned to one single project but rather to several projects or the overall portfolio. Nonetheless, it is an important point that projects can be distinguished by their resource synergies within the network. For example, in the case of our exemplary portfolio the knowledge that project 4 is the most central in terms of resource synergies is of significant value. Further, for project 3 at the end of the ranking, possibilities to leverage synergies could be investigated. This type of statement can also be applied to other projects. For our RDG, project 1 holds a substantial lead in the ranking of almost all values of α. Hence, issues on this project would probably cause substantial effects to the wider portfolio, especially when we assume a high intensity of network impact. This is also true for project 6, though a quite constant centrality score is assigned. Since other projects (2, 4, 7) become relatively less central for higher values of α, the importance of project 6 increases. Examining the ranking of project 4 in the RDG, we observe that it becomes comparatively less central with higher values of α. If we consider the impact of the network structure of the IT project portfolio at hand (Figure 5) to be important - i.e. we regard higher values of α as realistic - then project 4 is comparatively less central than it would be in a portfolio in which we regard the network structure as less important - i.e. we regard lower values of α as realistic. Similar observations can be made for other projects.

Alpha centrality delivers differing but comprehensible results for different values of α for the RSG and the RDG. Hence, we find it appropriate to analyze IT project networks in terms of resource interactions. Developing the ability to analyze both directed (RDG) and undirected (RSG) graphs is a significant step, particularly as it allows us to bring synergies and dependencies of resource sharing face to face. In IT, PPS processes such an analysis of resource interactions can reveal major insights. Depending on the assumed intensity of connectedness (represented by the value of α), projects and their resource interactions must be regarded differently. Assuming high resource interaction intensity (high value of α), the effects to the portfolio should be regarded more carefully as the impact of single projects can increase. What is more, the multifaceted nature of research interactions can be compared from different angles, providing new perspectives and insights when it comes to portfolio management and the classification of single projects in the context of an established portfolio. As we have seen, this can be especially helpful, not only in attempts to integrate candidate projects, but also when attempting to identify how new resource interactions may alter existing interactions and with them the entire project portfolio.

By ranking projects within a project portfolio, we provide an intuitive and novel means to classify candidate projects in terms of resource synergies and dependencies from a network perspective. Of particular note, our ranking reveals aspects of complex IT project networks that differ for resource synergies and dependencies, although our RSG and RDG are quite similar. Therewith, we also provide insights that offer decision support in the selection of candidate projects.

Discussion and Conclusion

The current body of literature does not appropriately account for effects caused by the network structure of IT project portfolios. Although resource interactions have been investigated relatively frequently in the existing literature, the differentiation of synergies and dependencies is hardly mentioned. To address this research gap we scanned the current body of literature on resource interactions, analyzed the respective literature on synergies and dependencies, and considered how a distinction could be applied. As a result, we formulated a generally applicable distinction of resource synergies and dependencies that allows us to classify the prevailing definitions of resource interactions and can also serve as the basis for other research in this field. We also derived from this classification the specific properties for resource synergies (symmetric relation) and dependencies (asymmetric relation) and modeled a resource synergy graph (RSG) and a resource dependency graph (RDG) on this basis. In doing so, we have extended the modelling procedure for project interactions. We are positive that a substantial amount of this modelling approach can be applied to other types of interactions and, hence, we see room for further research in this direction. We have also pointed out that a RSG and a RDG, as a structured graphical representation of reality, can themselves already reveal insights into the project portfolio structure and, with that, support strategic portfolio decision making (Killen and Kjaer 2012) by providing a concise overview. Generally speaking, our distinction between resource synergies and dependencies enables and supports two novel aspects of portfolio management. Firstly, it allows for the classification of single projects in a portfolio context and with this allows for a comparison with others. Secondly, it provides a holistic perspective on the prevailing resource interactions within the IT project portfolio. However, in circumstances where such networks become even more complex and a pure graphical representation becomes less supportive, we advise using network algorithms as a means of analysis.

Within the testing stage of our research (cf. Meredith et al. 1989) we used alpha centrality to rank projects in an IT project network. We faced the chicken-and-egg situation of not having real-world data as long as there is no effective method of real-world data analysis. Hence, as a first step of research in this direction, we have drawn on a realistic but exemplary IT project network. Based on centrality scores, our work offers new insights concerning resource interactions. Our results reveal that for resource synergies and dependencies the network effects can vary significantly, even for the same projects in two overly identical graphs (RSG and RDG). As synergies cannot be reasonably assigned to one particular project, we modeled these using undirected graphs. This leads to smaller differences in the centrality scores of single projects compared to the dependency ranking. In addition, the notion of transitivity together with directed edges leads to a clearer distinction between centrality scores in the dependency network. In other words, the resulting centrality scores for the RDG are more distinguishable and deviate more than for the RSG. This implies that it is more likely that a single project affects the entire project portfolio strongly because of its dependencies. Based on these findings, we suggest that from a management perspective it may be advisable to pay more attention to the potential effects of resource dependencies than to the effects of resource synergies when planning a project portfolio or selecting candidate projects. In addition, new interactions caused by candidate projects may significantly alter the entire network structure. In terms of limitations, we have so far only conducted quantitative testing of our method. Hence, as a next step of research we suggest the use of real-world data to test our method and facilitate deeper insights to resource interactions in IT project portfolios. For example, a case study that encompasses different organizations would allow us to directly compare different IT project portfolios, their resource synergies and dependencies. Thus, it would facilitate a deeper understanding of the effects of (resource) interactions in IT project networks.

Concerning alpha centrality, we confirm that it is an appropriate approach for IT project network evaluation (Wolf 2015) which enables the comparison of undirected and directed networks, at least to some extent. One limitation of alpha centrality is that it requires the adjacency matrix to have a principal eigenvalue to assure convergence, which may not always be the case, especially for sparse adjacency matrices, i.e. for networks with few interactions. Determining an appropriate choice of α for a specific network, as well as incorporating the exogenous impact (e.g. project budget) in the vector e, can be part of future work. The question how to come up with reasonable estimations for the intensity of interactions should also be addressed.

We considered IT project networks and resource interactions in particular, but did not quantify the impact of interactions in terms of (monetary) portfolio value or risk, which is another limitation of our approach. Consequently, a direction for further research would be to develop the proposed method in this regard. Finally, we point out that the effects of other interaction types on the IT project portfolio can be equally important, as interactions may function as a reinforcing factor. Hence, the incorporation of other types of interactions into our model to allow for a holistic IT project portfolio assessment is the subject to further research.

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