Systemic Risk in IT Portfolios – An Integrated Quantification Approach[1]

Completed Research Paper

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Abstract

Recent trends in digitalization, combined with continuous innovation pressure, have led to an increasing number of IT projects that are often accomplished within huge IT project portfolios. Although numerous IT project and portfolio evaluation and planning approaches have been developed and applied in companies all over the world, approximately 25% of IT projects still fail, which may result in a global value destruction of approximately 900 billion USD. One main reason for the numerous failures is the lack of transparency concerning dependencies within IT portfolios. This paper draws on graph theory to present a rigorous assessment of systemic risk that is based on different types of direct and indirect dependencies within IT portfolios. Based on this assessment, an integrated, novel, and quantitative approach to IT portfolio evaluation is presented that strives to mitigate IT project failures as it helps decision makers to evaluate their IT portfolios more adequately.

Keywords: ex ante IT portfolio evaluation, project dependencies, intra-temporal dependencies, inter-temporal dependencies, systemic risk, risk quantification, network analysis, α-centrality

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Introduction

New trends, such as digitalization, intensify the already high importance of information technology (IT) to companies all over the world. Additionally, recent technological developments and associated changes in customer expectations are forcing companies to develop innovative ideas and creative solutions (Nguyen and Mutum, 2012) that can be translated into a vast increase in IT projects to fulfill these demands. As a consequence, more and more IT projects are being split into several stand-alone but interrelated IT solutions with customer impact to satisfy this continuous demand for innovation. To address this development and the resulting increase in IT project portfolio complexity, a holistic approach the valuation of IT project portfolios, hereinafter referred to simply as IT portfolios, is crucial. Although there are already a number of approaches for the valuation of IT projects and portfolios, investments in planning techniques for IT projects and IT portfolios continue to increase (Gartner 2014). Nevertheless, an alarmingly high number of IT projects fail. Flyvbjerg and Budzier (2011) contend that approximately 16% of IT projects cause an on average budget deficit of approximately 200%. Moreover, project failure rates greater than 25% have been reported (Mieritz 2012). The failure of so many IT projects could result in a global value destruction of approximately 900 billion USD (Gartner 2013). Recent studies have shown that existing methods for IT project and IT portfolio evaluation might not be sufficient (Flyvbjerg and Budzier 2011; Radar Group 2012).

IT projects are usually planned and implemented within aggregated and quite extensive portfolios of several different IT projects, such as mobile application development projects, database restructuring projects, and large software development projects for business system applications. Therefore, they incorporate high-order dependencies, in contrast to projects that are accomplished in isolation or in pairs (Graves et al. 2003). Consequently, one major reason for IT project failures may be inadequate reflection upon and consideration of dependencies regarding shared assets between IT projects (CA Research 2008). This premise is supported by a questionnaire survey of 560 IT decision makers in Scandinavia, conducted by the Radar Group, which revealed that one reason for IT project failure is a lack of transparency regarding dependencies (Radar Group 2012). The management of such dependencies could help to reduce overall IT project costs and increase the benefits achieved by IT projects (Santhanam and Kyparisis 1996). However, many existing IT project evaluation methods consider neither dependencies associated with IT portfolios nor their associated risks. Although there are some approaches for IT project or IT portfolio evaluation (cf. Beer et al. 2013; Kundisch and Meier 2011; Lee and Kim 2001; Wehrmann et al. 2006) that do consider dependencies, they do not consider the specific characteristics of IT portfolio dependencies. Different types of dependencies and the prevalence of transitive dependencies are almost consistently neglected in existing IT portfolio evaluation methods. Furthermore, some approaches that do consider the dependencies of IT project portfolios in more elaborate ways fail to evaluate them quantitatively and are therefore not regarded as reasonable decision support tools for IT portfolio managers (Müller et al. 2015). Most approaches also lack feasibility for practical application (Zimmermann 2008), which further emphasizes the need from praxis for adequate means for IT portfolio evaluation that incorporate a detailed assessment of risk based on interdependencies among IT projects.

As stated by Benaroch and Kauffmann (1999), “a major challenge for information systems (IS) research lies in making models and theories that were developed in other academic disciplines usable in IS research and practice.” In fulfilling the need for a method for IT portfolio evaluation that incorporates a detailed assessment of risk based on inherent interdependencies, we consider IT portfolios as networks of interdependent nodes, where each node reflects an IT project and the arcs reflect dependencies between projects. We draw on concepts from sociological research based on graph theory that have already been applied to the analysis of several network-alike structures, in areas such as social network analyses (Wasserman and Faust 1994; Newman 2010), supply chain management (Kim et al. 2011; Fridgen and Zare Garizy 2015), and IT infrastructure management (Simon and Fischbach 2013). To be more precise, we focus on the application of centrality measures that identify the central nodes of networks based on their positioning and/or their connectivity to other nodes and are consequently considered suitable for use in assessing the systemic risk arising from dependencies among the nodes of the network, or rather, the projects in the portfolio. Furthermore, we integrated the resulting criticality score, derived from the centrality measure, to the existing classical portfolio theory approaches.

Thus, we are able to develop a novel and fresh approach for value-based IT portfolio evaluation that integrates costs, benefits, risks, and different types of dependencies in a thoroughly quantitative and feasible way. The appropriate consideration of different types of dependencies and in particular of transitive dependencies in IT portfolios is a main contribution of this research because these have been identified as important reasons for IT project failures but have not been sufficiently considered in previous research, to the best of our knowledge. The consideration of these dependencies is important for decision makers because it will result in better estimation of the values of IT portfolios. Better IT portfolio value estimation will make it possible for decision makers to request appropriate budget for IT portfolios and avoid the difficulty of applying for additional budget during project execution as a result of unseen dependency risks. Therefore, the results should empower decision makers to consider dependencies and associated risks accurately in their IT portfolio evaluations. Since, if considered properly, the risk associated with dependencies in some cases might result in a negative portfolio value (when costs and risk surpass benefits), this approach moreover reduces the risk of false investments.

To provide a relevant and rigorous approach to IT portfolio evaluation, we followed the recommendations of Hevner et al. (2004) and Gregor and Hevner (2013) and developed our approach as an artifact, according to their Design Science Research guidelines. To describe the *problem relevance* and the need for an integrated approach for value-based IT portfolio evaluation, we illustrate current developments and existing challenges in the motivation section. Based on a structured review of the literature and recent state-of-the-art articles, we furthermore explain and relate key terms associated with dependencies and summarize current methods for their appraisal in section 2. In section 3, we present our integrated approach step by step to ensure comprehensibility. To guarantee *research rigor*, the *artifact design* is based on well-established methods and theories prevalent in literature, extended or adopted to fit our purposes. We also performed some *evaluation* cycles during the development-phase to ensure rigor and relevance. We *evaluate* the artifact regarding *quality, utility* and *efficacy* in section 4. Therefore, we draw on simulation, which according to Hevner et al. (2004) is an established evaluation method. To demonstrate the applicability of our artifact, we moreover provide an application example and describe its benefits in comparison to other established theories and practices. Section 5 concludes the paper and includes a discussion of the limitations of our approach and future research needs.

Theoretical Background

For decades, IT project and IT portfolio evaluation and appropriate consideration of IT project dependencies have been highly relevant topics in research and practice. Hence, it is reasonable that over the last few decades, a great number of publications have been published on this subject. To develop a fresh approach that holistically assesses dependencies within a value-based IT portfolio evaluation, we need to understand and integrate three subtopics of research on the subject. Thus, we first present a general overview of methods for IT project and IT portfolio evaluation. We then identify and elaborate different types of dependencies before describing how they are currently appraised in literature. We performed a keyword-based search (using the terms dependency, interdependency, interaction, project, portfolio, information technology, information systems, model, method, requirements, approach, quantification, assessment, IT project, evaluation, value assurance, and valuation) of various data bases (AIS Electronic Library, EBSCOhost, EmeraldInsight, ProQuest, ScienceDirect, Wiley, Google Scholar, JStor, Springer, and ACM). Although this search identified many relevant articles, we found that most of these were already considered in the most recent articles summarizing the state of the art. On our first subtopic of IT project and IT portfolio evaluation methods, Beer et al. (2013) performed an extensive literature review as part of their research on an integrated project quantification method. The second subtopic, different types of dependencies, was outlined by Wolf (2015) and also, quite comprehensively, by Müller et al. (2015), who published a state-of-the-art article dedicated to different types of dependencies and their current appraisal. Therefore, based on our keyword-based search and the recently published state-of-the-art articles, we developed a brief, sound, and integrated overview of the existing literature. Our review, however, is structured to address all three of the aforementioned subtopics. For more detailed reviews of the literature on these subtopics, please refer to the articles of Müller et al. (2015), Wolf (2015), and Beer et al. (2013).

Methods for IT project evaluation and IT portfolio evaluation

It is important to note that the evaluation of IT portfolios typically includes the evaluation of IT projects. Furthermore, IT project evaluation methods are sometimes simply adopted to IT portfolio evaluation. Therefore, as it is almost impossible to differentiate strictly between IT project and portfolio approaches, this section gives only a brief overview of important IT project and portfolio evaluation methods, without distinguishing between them regarding their application within a project or portfolio context. There are indeed many approaches and methods in literature that address IT project and portfolio evaluation. Though, integrated evaluation approaches that consider benefits, costs, risks, and dependencies in a quantitative and feasible manner are quite rare, even though this has been identified as a highly relevant topic in research and practice (Müller et al. 2015). Existing approaches often account only for qualitative factors. Some models also use quantitative figures for the valuation of benefits and sometimes risks — but not, unfortunately, on a monetary basis. We present below a brief summary of some existing approaches to IT project and portfolio evaluation. Because the focus of this paper is on quantitative methods for IT project and portfolio evaluation, we focused on these types of approaches, although we are aware that many publications are focused on a more general evaluation that also accounts for qualitative factors.

Frequently used tools for IT project evaluation are so-called scoring models (e.g., Walter and Spitta 2004; Zangemeister 1976), which identify and weight all relevant evaluation criteria for a specific IT project. The resulting scores are aggregated to provide an overall value that enables the comparison of different alternatives. The Balanced Scorecard by Van Grembergen and De Haes (2005) is also a type of a scoring model. The cause-and-effect relations between key qualitative and quantitative figures are described to identify two general types of key figures: performance drivers and output figures. The project is evaluated on the basis of the degree of target achievement of each key figure. The so-called WARS-Model (Ott 1993) has the ability to estimate benefits and costs crudely by classifying them into three categories according to their tangibility. The risk aversion of decision makers is taken into account by assessing different risk stages for optimistic or pessimistic decision makers. A more quantitative approach for IT project evaluation was presented by Schumann (1993), whose approach is based on functional chains. In this approach, benefits can be expressed in monetary terms by focusing on their effects. However, this approach lacks a proper quantitative integration of risks and dependencies. Another approach that considers quantitative values for costs, benefits, risks, and dependencies in an integrated manner is the so-called benefits management approach of Beer et al. (2013). Using preference functions, they derive a risk-adjusted monetary project value. This has been proven a feasible approach by business experts. Like the approach proposed by Beer et al. (2013), many approaches for IT project and portfolio evaluation refer to or are based on the well-known methods of decision theory, as for instance μ/σ-decision rules (which means that the investment decisions of decision makers in companies are reached by comparing the expected values of investments while taking into consideration their respective risks). This seems to be an adequate way to derive a risk-adjusted IT portfolio value, although some approaches (e.g. Beer et al. (2013)) only applied these methods in a single project instead of a project portfolio context.

Despite the vast number of different approaches for IT project and portfolio evaluation in research and practice, to the best of our knowledge, there is no integrated, value-based evaluation approach that also considers the specific characteristics of dependencies between projects in an IT portfolio.

Different types of dependencies

As mentioned before, there are different types of dependencies between the projects within IT portfolios. This fact is also reflected in literature. We found that some articles just mention certain types of dependencies, while others try to integrate and structure these types of dependencies in specific frameworks. Most articles (e.g., Lee and Kim (2001); Santhanam and Kyparisis (1996); Tillquist et al. (2004), Zuluaga et al. (2007)) describe resource dependencies, technical dependencies, and dependencies regarding benefits. A further segmentation of resource dependencies distinguishes between personal and technical dependencies (Wehrmann et al. 2006). Personal dependencies refer to projects competing for personnel resources, and technical dependencies refer to projects competing for technical resources. In contrast to the segmentation provided by Wehrmann et al (2006), Kundisch and Meier (2011) developed a framework for subdividing resource dependencies into allocation, performance, and sourcing dependencies.

Technical dependencies are defined in many different ways in the literature, but in general, two major categories can be differentiated: technical dependencies can either arise from two projects competing for technical resources, as described by Wehrmann et al. (2006), or they can represent the fact that a specific project requires input from a precedent-associated project. Benefit dependencies may also be considered as synergies (Buchholz and Roth 1987) and can be realized if the value of at least one of the concerned projects increases when being implemented simultaneously with another. Examples of such synergies could be databases that have been built for specific projects but can also be used for other projects. Other examples are accumulated expert knowledge that is relevant to more than one project and the reuse of code fragments for two similar software development projects.

A well-established way of structuring dependencies is provided by Wehrmann et al. (2006) and Zimmermann (2008), who distinguish between intra- and inter-temporal dependencies. Intra-temporal dependencies refer to the dependencies of different projects that are assigned to the same period in time. Intra-temporal dependencies are presumed to encompass structural dependencies and resource dependencies (Wehrmann et al. 2006). Considering the number of related published articles, intra-temporal dependencies seem to be well recognized in literature, especially within the spectrum of Operations Research (e.g., Aaker and Tyebjee 1978; Carraway and Schmidt 1991; Fox et al. 1984; Gear and Cowie 1980; Medaglia et al. 2007; Kundisch and Meier 2011; Lee and Kim 2001; Santhanam and Kyparisis 1996; Stummer and Heidenberger 2003). In general, there is a common understanding in literature about the causes of resource dependencies in IT projects. They are presumed to arise from the sharing of scarce resources, such as personnel, hardware (servers), and software (database logic) resources (Graves and Ringuest 2003; Santhanam and Kyparisis 1996). Structural dependencies can be divided into the subcategories of process dependencies, data dependencies, and IT-functionality dependencies if two or more IT projects are, for example, based on the same processes, use the same data, or apply the same IT functionalities (Wehrmann et al. 2006).

Inter-temporal dependencies, in contrast, refer to dependencies between different projects that are assigned to different periods in time. Thus, inter-temporal dependencies describe a coherence by which a succeeding project is based on a preceding one. These dependencies can be distinguished as logical and technical or rather technological dependencies (Maheswari and Varghese 2005, Santhanam and Kyparisis 1996). Logical dependencies or integrative coherences are further subdivided into hard and soft dependencies by Bardhan et al. (2004). Other authors distinguish inter-temporal dependencies either in inter-temporal output interactions (e.g., Pendharkar 2014) or in inter-temporal output–resource interactions (e.g., Dos Santos 1991; Kumar 1996; Panayi and Trigeorgis 1998; Taudes 1998; Taudes et al. 2000). Most approaches, however, focus on output–resource-based dependencies, whereas output dependencies without the resource context are barely included.

To provide an overview of different types of dependencies and to enhance comprehensibility, Figure 1 summarizes the different types of dependencies in a revised framework based on those by Wehrmann et al. (2006) and Wolf (2015).

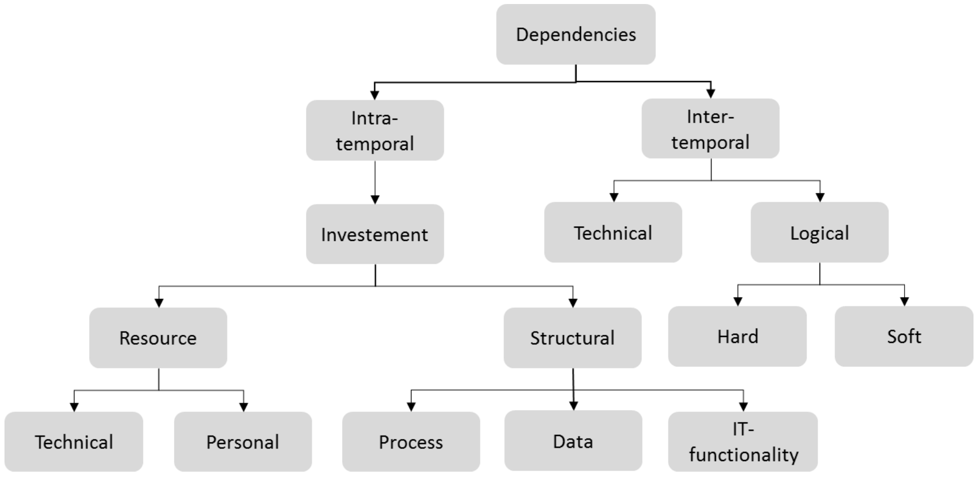

Figure 1. Dependencies in IT Portfolio

Methods for consideration of dependencies

To provide a more structured overview of existing research regarding the current appraisal of different types of dependencies, we structured this section according to the well-established classification of intra- and inter-temporal dependencies as described by Wehrmann et al. (2006).

Intra-temporal dependencies

Various approaches to account for intra-temporal dependencies among IT projects and IT portfolios exist. One approach is to integrate them as auxiliary conditions in an optimization model (Kundisch and Meier 2011; Lee and Kim 2001; Santhanam and Kyparisi 1996). Another approach, used by Beer et al. (2013), Butler et al. (1999), and Wehrmann et al. (2006), for example, is to draw on the portfolio theory of Markowitz (1952) to determine a risk- and return-optimized IT portfolio using the normalized covariances of the corresponding IT projects. A modified discounted cash flow approach, presented by Verhoef (2002), considers dependencies implicitly while focusing on cost and time risks for a given interest rate. However, many of these methods fall short to some degree because of their underlying financial restrictions (Zimmermann et al. 2012) or because they often do not consider the dependence structure of the whole portfolio but rather focus only on the dependencies between two specific projects. A wide number of publications concerning intra-temporal dependencies, particularly from problem-solving domains such as Operations Research, do not focus on ex ante evaluation alone (meaning that an evaluation takes place prior to the start of an IT project or IT portfolio) but rather provide procedures to consider dependencies continuously during the portfolio planning process. Thus, the contributions of these papers are methods, models, or algorithms that are aimed at solving specific capacity problems in the context of intra-temporal dependencies, rather than integrating these intra-temporal dependencies in the IT portfolio evaluation (Aaker and Tyebjee 1978; Carazo et al. 2010; Carraway and Schmidt 1991; Cho and Kwon 2004; De Maio et al. 1994; Doerner et al. 2006; Eilat et al. 2006; Fox et al. 1984; Gear and Cowie 1980; Klapka and Pinos 2002; Lee and Kim 2001; Liesiö et al. 2008; Medaglia et al. 2007; Nelson 1986; Santhanam and Kyparisis 1996; Stummer and Heidenberger 2003; Weingartner 1966).

Inter-temporal dependencies

Inter-temporal dependencies within IT portfolios are most commonly assessed by using real options-based approaches, which stem from options theory in the financial sector. Several methods described in literature are based on the Black–Scholes model, and some use binomial trees to represent inter-temporal dependencies (cf. Bardhan et al. 2004; Benaroch and Kauffmann 1999; Dos Santos 1991; Taudes et al. 2000). As both approaches were originally developed in the financial sector, they feature specific restrictions and assumptions that are only partly fulfilled in the context of IT portfolios (Emery et al. 1978; Schwartz and Zozaya-Gorostiza 2003). Therefore, their applicability to inter-temporal dependencies in the context of IT portfolios is doubtful. For a more detailed discussion of whether real options approaches are applicable in the IT portfolio context, please refer to Diepold et al. (2009) and Ullrich (2013), who present a detailed investigation into the transferability of these methods to the consideration of dependencies in IT project and IT portfolio evaluation.

There have also been some attempts to integrate the two types of dependencies, namely inter- and intra-temporal dependencies (cf. Bardhan 2004, Pendharkar 2014). However, based on the outlined examination of current approaches for IT project and portfolio evaluation, different types of dependencies in IT portfolios, and their current appraisal, we can conclude that different types of dependencies are almost always considered in isolation from one another. However, because in reality different types of dependencies are interconnected and can be found in every IT portfolio, they have to be considered in a holistic way, which is not done by any approach proposed so far (cf. Müller et al. 2015). Moreover, we found that none of the existing IT portfolio evaluation and management techniques explicitly considers transitive dependencies between IT projects within IT portfolios. An assessment of transitive dependencies is essential to an appropriate risk assessment and value-based evaluation in these network-like structures. Therefore, none of the investigated approaches can be considered completely appropriate for the purpose of integrated value-based evaluation of IT portfolios with consideration of their characteristic inherent dependency structures.

Modeling Procedure, Assumptions, and Requirements

In this section, we present an integrated, quantitative approach for holistic IT portfolio evaluation. This approach not only considers different types of dependencies but also accounts for transitive dependencies. We first introduce an integrated approach that is capable of accounting for the costs, benefits, risks, and dependencies of IT projects in a portfolio context. We then describe how this approach can be expanded to account for intra- and inter-temporal dependencies within an IT portfolio. We introduce a procedure to quantify the strength of intra- and inter-temporal dependencies and aggregate the strength assessments into a uniform dependency value. Based on this value and considering the IT portfolio as an IT project network, we use α-centrality to measure and quantify the dependence structure of an IT portfolio, including inherent transitive dependencies. Based on this procedure, we strive to determine a risk-adjusted IT portfolio value that considers costs, benefits, risks, and dependencies in a comprehensive und quantitative manner.

An Integrated view of IT project evaluation

For the purpose of quantitative assessment of an IT portfolio, we draw on an approach inspired by the portfolio theory of Markowitz (Markowitz 1952). More specifically, we adapt and modify the integrated approach of Beer et al. (2013), who integrate benefits, costs, risks, and a superficial kind of dependencies to determine a risk-adjusted IT project value using the preference function. This function is an established method in decision theory (Bernoulli 1738; Bernoulli 1954; Markowitz 1952; von Neumann and Morgenstern 1947) and has been used in a considerable number of IT project-related studies (cf. Bardhan et al. 2004; Fogelström et al. 2010; Fridgen and Müller 2011; Hanink 1985; Zimmermann et al. 2008). According to Beer et al. (2013), this risk-adjusted IT project value Φ is based on the overall cost C of the complete IT project i and the aggregated sum $\Sigma\mu_i$ of all projects' expected benefits μ_i. In a manner similar to that proposed by Markowitz, dependencies are considered in terms of the Bravais–Pearson correlation coefficient ρ_{ij} and offset within one term for the overall risk adjustment $\Sigma\Sigma\, \sigma_i\sigma_j\rho_{ij}$. The Bravais–Pearson correlation coefficient is a statistical measure of the linear correlation between two variables, or in the case of Beer et al. (2013), between two benefits of an IT project. Its value lies between -1 and 1, where -1 indicates a perfect negative linear correlation, 0 indicates that there is no linear correlation, and +1 indicates a perfect positive linear correlation. Since a negative correlation value decreases the overall value of risk adjustment, it is considered to represent synergies between the respective benefits. In contrast, a positive value is considered to refer to any other kind of dependencies that consequently increase the overall value of risk adjustment or rather the risk discount to the overall project value.

The other parameters of the term of risk adjustment are σ_i and σ_j representing the variances of the values of the expected benefits. Furthermore, to account for the level of risk aversion of the decision maker, this risk adjustment term is weighted by a risk aversion parameter, in our case referred to as γ. The risk aversion parameter γ is a linear transformation of the Arrow–Pratt characterization of absolute risk aversion (Arrow 1971) and reflects a decision maker's attitude toward risk in uncertain situations. The value of γ increases with the decision maker's level of risk aversion, which means that the higher the value of γ is, the more risk-averse the decision maker is. Highly risk-averse decision makers tend to invest in less risky investment options, whereas less risk-averse decision makers tend to invest in more risky investment options. In practice, the degree of risk aversion can be determined at the executive level using an elaborate questionnaire, according to Sauter (2007) and Beer et al. (2013). Based on this considerations, the risk-adjusted IT project value can be expressed by the following preference function:

$$\Phi(\mu,\sigma) = -C + \Sigma\,\mu_i - \gamma\,\Sigma\Sigma\,\sigma_i\sigma_j\rho_{ij} \qquad (1)$$

The approach described above is used for the evaluation of single IT projects with a particular focus on benefits management (through the integration of costs, benefits, dependencies among benefits, and risks). This approach lacks direct applicability in an IT portfolio context and does not take into consideration the different types of dependencies described previously. However because this approach is inspired by Markowitz portfolio theory, it can easily be adapted to the evaluation of IT portfolios. In contrast to Beer et al. (2013), we take a cash flow-based perspective, in a manner similar to that described by Fridgen et al. (2015), and state the following assumption:

Assumption 1: The cash flows of an IT project are normally distributed random variables $cf_i \sim N(\mu_i, \sigma_i)$.

Although project cash flows might not be normally distributed in every case, it is common in IT portfolio management to assume that they are (cf. Fridgen and Müller 2011, Fridgen et al. 2015; Wehrmann et al. 2006; Wehrmann and Zimmermann 2005; Zimmermann et al. 2008). Based on this assumption, we can derive the distribution parameters μ_i and σ_i for each IT project, where $i = 1\dots n$ indicates the respective IT project of the IT portfolio. Consequently, μ_i represents the expected value of IT project i, and σ_i indicates the variance of this expected value, or rather, the corresponding risk.

Whereas Beer et al. (2013) and Fridgen et al. (2015) took dependencies into consideration by means of a correlation coefficient between every pair of underlying investigation objects and derive an overall term for risk adjustment, we distinguish between an IT project risk term $\Sigma\,\sigma_i^2$ that refers to the risk related to a particular IT project and an IT portfolio risk term $\Sigma\Sigma\,\sigma_i\sigma_j\tilde{\rho}_{ij}$ that refers to the systemic risk originating from the inherent direct and indirect dependencies between IT projects in the IT portfolio. However, the Bravais–Pearson correlation coefficient $\rho_{ij}$was developed to determine the values of coherence based on statistically measureable historical data (e.g., covariance of the shares in the stock market), which implicitly describe transitive dependencies as well. However, in the context of the ex ante evaluation of IT projects, historical data for the statistical calculation of covariance are usually not available. Instead, in this case, the corresponding prevalent values are mostly represented by ex ante expert estimations of project dependencies. Because experts normally are asked for pairwise estimations of project dependencies, they usually are not aware of possible transitive dependencies, which are consequently mostly neglected in the resulting estimated covariance matrix of a corresponding IT portfolio. Therefore, the Beer at al. (2013) approach is able to consider dependencies in a very ingenuous way only, and is neither able to consider different types of dependencies nor transitive dependencies.

$$\Phi^*(\mu,\sigma) = \sum_i \mu_i - \gamma \sum_i \sigma_i^2 - \gamma \sum_i \sum_{j \neq i} \sigma_i \sigma_j \tilde{\rho}_{ij} \tag{2}$$

As we strive to consider both, different kinds of dependencies as well as direct and transitive dependencies, we refrain from using the classical Bravais–Pearson correlation coefficient ρ_{ij}. Instead, we consider a value $\tilde{\rho}_{ij}$ with $0 \leq \tilde{\rho}_{ij} \leq 1$ to reflect the aggregated strength of dependencies between pairs of IT projects $i, j = 1\dots n$. We moreover draw on *α-centrality* to determine a corresponding IT portfolio risk term $\Sigma\Sigma\,\sigma_i\sigma_j\tilde{\rho}_{ij}$ that accounts not only for direct but also for transitive dependencies. However, before we are able to do so, we need to assess the different types of dependencies between pairs of IT projects in the IT portfolio and aggregate them into a single dependency value that we can quantify.

Assessing different types of dependencies

As described previously, there are different types of dependencies within an IT portfolio. We use the distinction made by Wehrmann et al. (2006) between intra- and inter-temporal dependencies. However, we do not consider synergies between different IT projects within our term of risk adjustment. This seems plausible though, since the coherence between IT projects have been reported to rather exist due to dependencies than to synergies (e.g. Häckel and Hänsch 2014). In the case of intra-temporal dependencies, IT projects can be dependent on each other because they share resources (e.g., personnel) or infrastructure (e.g., data or databases). Therefore, we use the word “asset” to refer to either resources or infrastructure components that are planned for an IT project. In addition, each IT project can be separated into many interdependent activities. Accordingly, the dependencies between two IT projects can be considered as the result of dependencies on a more granular level. To facilitate this characterization, we do not distinguish between different levels of granularity; rather, we consider an IT project to be the most granular level, which cannot be divided into further distinct categories of activities. Furthermore, we assume that every IT project is assigned to one specific period of time t, i.e., that the start and end date of the project are within the same period. In reality, IT projects often take place over several months. Consequently, we assume that these IT projects can be subdivided into smaller ones that can be assigned to specific periods of time. An IT portfolio usually has a specific planning horizon and encompasses IT projects that take place during many of the covered periods $t = 1\dots T$. There can also be 1 to n IT projects within the same period of time, because there might be more than one IT project going on at the same time, even in a small company.

There are two different perspectives on how assets are shared between IT projects: the asset pooling perspective and the asset accounting perspective. The *asset pooling perspective* considers different IT projects to draw on the same pool of assets. A specific asset can be used by $[1 \ldots n]$ IT projects. However, if the IT projects take place at the same point in time, they have to share the asset, and consequently, each IT project only accounts for a specific percentage of the asset between $[0\% \ldots 100\%]$. At each point in time, the sum of the asset shares of an IT project cannot exceed 100%. If asset a_1 is shared between IT projects $i, j,$ and k and the shares of the IT projects for asset a_1 are $a_{1_i}, a_{1_j},$ and a_{1_k}, then $a_{1_i} + a_{1_j} + a_{1_k} \leq 100\%$. If the asset is not shared between two or more IT projects, there is no dependency caused by this asset. This coherence is illustrated in Figure 2.

This perspective, however, seems unfavorable in the case of inter-temporal dependent IT projects. Because the asset pool and an IT portfolio are strictly segregated, an IT project would have to be considered an asset to serve as an input to another IT project. Consequently, it would have to be considered as an asset and an IT project at the same time, which seems inappropriate for the purpose of this research.

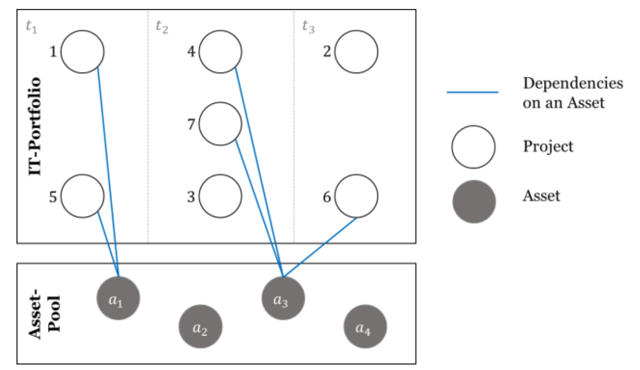

Figure 2. Asset Pooling in an Exemplary IT portfolio

In this context, the *asset accounting perspective* provides a more appropriate solution to the simultaneous consideration of intra- and inter-temporal dependencies. According to this perspective, assets are assigned directly to IT projects that depend upon them (cf. Figure 3). Consequently, $[1 \ldots k]$ assets can be allocated to $[1 \ldots n]$ IT projects with percentage shares between $[0\% \ldots 100\%]$. However, in this case as well, the sum of the asset shares of an IT project cannot exceed 100% at any point in time. If the asset is assigned to one specific IT project alone, there is no dependency to another IT project caused by this asset. For instance, if a software developer (a personnel resource) is allocated exclusively to project i, other projects have no dependency on project i associated with this asset.

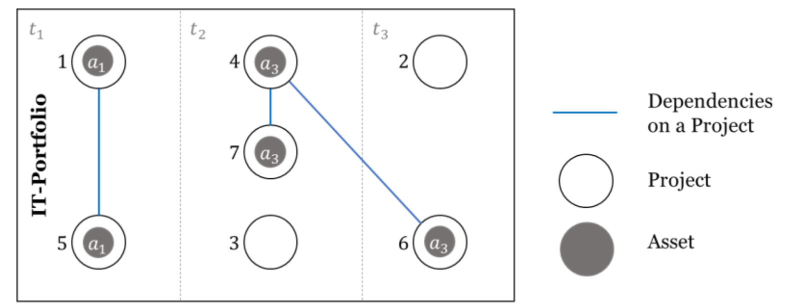

Figure 3. Asset Accounting in an Exemplary IT portfolio

As Figure 3 shows, according to the asset accounting perspective, dependencies are considered to exist between different projects but not between projects and assets. Therefore, in contrast to the asset pooling perspective, inter-temporal dependencies can easily be considered. However, it should be noted that an asset that is assigned to two consecutive IT projects (cf. projects 4 and 6 in Figure 3) does not constitute an inter-temporal dependency, because of our assumption that every IT project is assignable to one specific period of time. Therefore, if an asset is assigned to two projects that take place at different points in time, it does not cause any dependency, as the first project will have finished using the asset before the second project starts to use it.

In addition to the dependency caused by sharing a specific asset between IT projects, assets are typically able to cause a different type of risk: a risk associated with the availability of the asset itself. Each type of asset has an inherent risk of failure, which is independent of whether it is shared between different IT projects. In the context of personnel resources, the availability of a software developer, for instance, depends on the software developer's health. Because this type of risk does not originate on the dependencies of different projects on specific assets, it is not considered within the IT portfolio risk term and thus is not considered in the following discussion.

Aggregating different types of dependencies into a single value

Since we strive to consider both inter- and intra-temporal dependencies, we need to aggregate them into a single quantitative value. Therefore, we take the asset accounting perspective, as described above, and draw on the idea presented by Wolf (2015), considering the IT portfolio to be an IT project network. Consequently, we model the IT portfolio as a connected and directed graph. Each IT project $i = 1 \dots n$ in the portfolio is represented by a node. A dependency (inter-/intra-temporal) between IT projects $i, j = 1 \dots n$ is represented by a directed edge between these IT projects. Inter-temporal dependencies are represented by a directed edge pointing from the dependent IT project to the IT project upon which it depends. Logically, when an IT project i is inter-temporally dependent on an IT project j, IT project j cannot be inter-temporally dependent on IT project i. Intra-temporal dependent IT projects share an asset within the same period of time. Hence, as these IT projects are affected at the same time, there is an edge from IT project i to IT project j and an edge from IT project j to IT project i. We define the weight of an edge in the graph as representing the strength of the dependency between two IT projects.

Figure 4 illustrates an example IT portfolio with inter- and intra-temporal dependencies between IT projects based on an IT project network perspective.

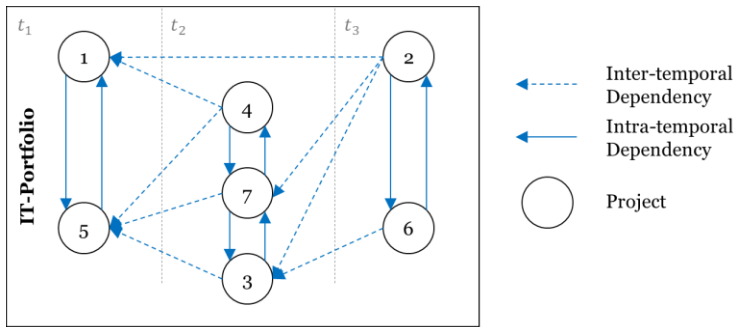

Figure 4. Exemplary IT portfolio

To aggregate intra- and inter-temporal dependencies to a single value, we quantify the strengths of these dependencies based on the same underlying factor. We identify "time" as the common factor that enables a quantitative determination of inter- and intra-temporal dependencies. More specifically, we consider the relative time lag that a particular IT project can cause to the other projects that depend on this particular project. We describe the quantification of intra- and inter-temporal dependencies below.

Intra-temporal Dependencies

In the case of intra-temporal dependencies, the relative time lag refers to the time that an IT project—given that all assets are available—would require for implementation. The lag describes the prolongation of this implementation time due to the struggle between two different IT projects regarding one critical asset. We thus consider two types of assets: uncritical assets a^{uc} that are not simultaneously required by different IT projects and critical assets a^{c} that are simultaneously required by at least two different IT projects. We strive to quantify the time lag in case all, none, or some percentage of the critical assets of a particular IT project are available. However, as the extent of such a time lag can differ based on the assets' importance to a particular IT project and the size of the project, we denote its value relative to the project size. Therefore, we consider each IT project $i = 1 \dots n$ to have a size S^{p_i}, which is usually measured in time-related units, such as full-time equivalents (FTEs). However, we consider project size to represent the overall duration of the implementation of an IT project in working hours. Based on the average working hours of a specific company, this value can easily be converted into FTEs. Using the project's size, we are able to determine a project's duration D^{p_i} based on the number of assets that are assigned to the IT project.

Assumption 2: The coherence between the duration of an IT project and its assigned assets is linear.

Although this assumption might not be realistic for each type of asset, it seems plausible for at least the most important intra-temporal dependencies, and it is easy to grasp. Therefore, we consider it to be an appropriate assumption for the first step toward aggregation and consistent quantification of different types of intra-temporal dependencies. Based on this assumption, we are able to quantify the intra-temporal dependencies between two different IT projects. We calculate the prolongation of the project duration resulting from the reciprocal shortfall of required critical assets according to the following equation:

$$D_k^{p_i} = \frac{S^{p_i}}{(a_k^{uc} + \vartheta_k \cdot a_k^c)} \tag{3}$$

To do so, we use equation 3 to calculate two different scenarios, which will be related afterward. In the first (max-)scenario, we calculate the duration of the project for the case in which all planned assets a_k, uncritical assets a_k^{uc}, and critical assets a_k^c in each asset category $k = 1 \dots l$ (e.g., resources and infrastructure) are available. Whereas uncritical assets a_k^{uc} are presumed to be available without having any other project competing for them, the availability of critical assets a_k^c is reflected by the parameter ϑ_k, where $0 \leq \vartheta_k \leq 1$. This parameter represents the percentage of availability of the assets of a specific asset category. Consequently, in the case of the first scenario, $\vartheta_k = 1$ for each asset that is assigned to the IT project. In the second (min-)scenario, we calculate the duration of the project in the case of a rival IT project being given preference regarding all critical assets a_k^c. In this case, $\vartheta_k = 0$ for all competed-for assets. Combining the resulting values for the two scenarios, we can calculate the percentage of the project that can be accomplished with the available assets in the initially planned time frame (the originally planned period for the project duration when all assets are available). Consequently, we can determine the percentage of the project that remains incomplete during the initial time frame and is caused by asset category $k = 1 \dots l$ as follows:

$$\Delta D_k^{p_i} = 1 - \frac{D_{k_{max}}^{p_i}}{D_{k_{min}}^{p_i}} \tag{4}$$

The result of equation (4) is the percentage of project i that remains incomplete because its critical assets are unavailable and blocked by project j. Therefore, the percentage of project i that might remain undone as a result of the critical asset dependency on project j is the weight of the edge from project i to project j or rather the strength of the corresponding dependency. Consequently, equation (3) quantifies the effects of IT projects competing for one or more critical assets. However, as mentioned before, equation (3) and (4) do not consider the prolongation of the project duration resulting from a shortfall of an assets (uncritical or critical). This is considered to be part of the project's individual risk (σ_i) in equation (2).

To illustrate the outlined coherence, we refer to Figure 3, where p_1 and p_5 have intra-temporal dependencies caused by a single asset category a_1. Let p_1 be a software development project with an approximate size of approximately 250 working hours, and let p_5 be a smaller project with an approximate size of 150 working hours. Project p_1 requires five assets a_1 from category $k = 1$ to be completed on schedule, and p_5 requires three assets. However, two specific software developers are required for both projects and thus are critical assets. Therefore, the critical assets $a_1^c = 2$ for both projects, whereas $a_1^{uc} = 3$ for p_1 and $a_1^{uc} = 1$ for p_5. According to equation (3), we can calculate the (max-)scenario with $\vartheta_1 = 1$ and the (min-)scenario with $\vartheta_1 = 0$ and relate the resulting values $D_{1_{min}}^{p_1} = 83.33$ and $D_{1_{max}}^{p_1} = 50$ to derive $\Delta D_1^{p_1} = 0.4$, which can be considered the percentage of project p_1 that remains incomplete during the initially planned time frame due to the critical asset category $k = 1$.

The dependency of project p_1 on project p_2 is a result of the dependency on asset category k_1. Consequently, the weight of the edge from project p_1 to project p_2 is equal to 0.4.

In the case in which there is only one critical asset category, such as that described above, $\Delta D_k^{p_i}$ is considered to represent the quantification w_{ij} of the intra-temporal dependency between the dependent project p_i and another project p_j upon which it depends due to the specific asset category. However, if there are multiple critical asset categories $k = 1 \dots l$, we need to aggregate these categories to derive a single value for intra-temporal dependencies. In this case, $w_{ij} = \sum_{k=1}^{l} \Delta D_k^{p_i}$. However, this can potentially result in values of $w_{ij} > 1$. Because $w_{ij} = 1$ reflects the maximum dependency of 100%, we set $w_{ij} = 1$ for each aggregated value $w_{ij} > 1$.

Inter-temporal Dependencies

Inter-temporal dependencies are considered over the whole planning horizon of the IT portfolio. If two projects are inter-temporally dependent, they are assigned to different points in time that do not necessarily have to be consecutive. According to the precedence diagram method (Project Management Institute 2009), inter-temporal dependencies can be distinguished according to their start and finish points as follows:

- Finish-to-start (FS): The start of the successor project depends upon the completion of the predecessor project. Because the successor project is dependent on the result of the predecessor project, any delay in finishing the predecessor project can cause a delay in completion of the successor project. Consequently, we consider this as an inter-temporal dependency in the sense of our paper.
- Finish-to-finish (FF): The completion of the successor project depends on the completion of the predecessor project. This dependency describes a coherence where the completion of the succeeding project requires the preceding project to be completed to a specific extent. Since this dependency might cause a prolongation of the succeeding project, we consider it as an inter-temporal dependency in the sense of our paper.
- Start-to-start (SS): The successor and predecessor project should start at the same time and hence are allocated to the same period. As in this case there is no dependency between the successor and the results of predecessor project, we do not consider it as inter-temporal dependency in the sense of this paper.
- Start-to-finish (SF). The completion of the successor project depends on the start of the predecessor project. This implies that the predecessor project must be started before the successor project can be finished. Since this case does not reflect any kind of dependencies between the results of the predecessor project and the successor project either, but is mainly an issue for scheduling purposes, it is not considered as inter-temporal dependency in the sense of this paper.

In summary, we distinguish between only two types of inter-temporal dependencies: FS and FF dependencies, where incidents by predecessor projects might cause prolongations of successor projects, taking place at future points in time. As in the case of intra-temporal dependencies, we use the relative time lag to describe the prolongation of the project implementation time due to inter-temporal dependencies. In particular, we assess inter-temporal dependencies by calculating the relative prolongation of the project implementation of the succeeding project p_2 based on a delay in a preceding project p_1 (cf. Figure 4). In a case in which there is an FS dependency between p_2 and p_1, project p_2 cannot start before project p_1 has been finished. Therefore, we consider the strength w_{ij} of this dependency to be 100% and consequently declare $w_{21} = 1$. In contrast, if there is an FF dependency between p_2 and p_1, the completion of p_2 depends on the completion of p_1. Considering this coherence to be valid for partial completion as well, we can determine the strength of this type of dependency from the percentage of the predecessor project that has to be completed before the successor project can be completed. For example, if 60% of p_1 need to be completed before p_2 can be completed, we determine the strength w_{ij} of this dependency to be 60% and consequently declare $w_{21} = 0.6$.

Quantifying the dependence structure of IT portfolios based on α-centrality

As mentioned before, we strive to determine an IT portfolio risk term $\Sigma\Sigma\ \sigma_i \sigma_j \tilde{\rho}_{ij}$ that accounts for both direct and transitive dependencies in an IT portfolio. Therefore, we employ the idea presented by Wolf

(2015), considering an IT portfolio to be an IT project network, where each node represents a project and each arc represents a dependency. Wolf (2015) identified the following five requirements that a centrality measure has to fulfill to be applicable in the context of IT portfolios:

1. The measurement accounts for directed relations between projects.
2. The result of the measurement for a specific project increases with the strengths of the relations with dependent projects.
3. The result of the measurement for a specific project increases with the number of directly dependent projects.
4. The measurement accounts for transitive dependencies, as the result increases with the number of indirectly dependent projects.
5. The result of the measurement of a specific project increases with the importance of directly and indirectly dependent projects.

Based on these requirements, Wolf (2015) introduced some common centrality measures and investigated whether and to what extent they are appropriate for use in the quantification of dependencies in IT portfolios. The result of this investigation was that α-centrality was identified as the most suitable measure for quantifying dependencies in IT portfolios. We consequently use α-centrality to assess the network dependence structure and the corresponding inherent systemic risk. According to Wolf (2015), α-centrality accounts not only for direct dependencies, such as the number of directly dependent projects, but also for indirect or transitive dependencies. It thereby considers more interconnected and therefore critical projects to contribute more strongly to the criticality of the projects upon which they are dependent than projects that are less critical (Wolf 2015). In the following discussion, we briefly introduce the elements of α-centrality and illustrate how the concept can be adapted to the derivation of an IT portfolio risk term that can be used within an integrated quantification approach. α-centrality can be calculated according to the following equation:

$$x = (\boldsymbol{I} - \alpha * \boldsymbol{A}^T)^{-1} * \boldsymbol{e} \tag{5}$$

Presuming the arcs of the IT project network to be weighted, the elements w_{ij} of the $n \times n$ adjacency matrix $\boldsymbol{A}$ represent the weighted conjunctions of the network, or rather, the strengths of the corresponding IT project dependencies. We previously outlined how we derive w_{ij} for intra- and inter-temporal dependencies. These values can be considered equivalent to the pseudo correlation values ρ_{ij} of (1), which represent the linear dependencies between every pair of investigation objects (e.g., IT projects), based on expert judgments. Therefore, we consider w_{ij} to equal $\tilde{\rho}_{ij}$ in our IT portfolio risk term $\Sigma\Sigma\, \sigma_i \sigma_j \tilde{\rho}_{ij}$. The remaining elements in equation (5) are the identity matrix $\boldsymbol{I}$ and the scalar $\alpha > 0$. The latter is an arbitrary ratio between the endogenous status of the nodes (projects), which is calculated based on the network (dependency) structure, and the exogenous status of the nodes, which can be arbitrarily assigned based on the vector $\boldsymbol{e}$. The parameter α can take values in the range of $0 < \alpha < \lambda_1^{-1}$, where λ_1^{-1} is the maximum value of the eigenvector of the adjacency matrix $\boldsymbol{A}$. Most researchers choose a value for α that is close to the maximum value of λ_1^{-1} (Bonacich and Lloyd, 2001) because this choice maximizes the consideration of the endogenous character, or rather, the network or dependency structure. The exogenous status represented by the vector $\boldsymbol{e}$ makes it possible to assign a value to each node in the network, independent of the actual network structure described by the adjacency matrix $\boldsymbol{A}$. Within an IT portfolio context, this exogenous status might, for instance, be the risks or the sizes of the projects. To integrate the dependency values w_{ij} or $\tilde{\rho}_{ij}$in a risk measure that is comparable to established approaches like the one of Beer et al. (2013), we in this case consider the estimated (not normalized) covariance of the IT projects (which do not account for transitive dependencies) to be the exogenous factor in the α-centrality calculation. Since we strive to derive an according IT portfolio risk term $\Sigma\Sigma\, \sigma_i \sigma_j \tilde{\rho}_{ij}$, each dependency values $w_{ij} = \tilde{\rho}_{ij}$ of the adjacency matrix $\boldsymbol{A}$ needs to be multiplied by the respective covariance $\sigma_i \sigma_j$ of a corresponding $n \times n$ matrix $\boldsymbol{E}$. Therefore, the exogenous vector $\boldsymbol{e}$ of α-centrality needs to be replaced by the described matrix $\boldsymbol{E}$ whose elements $\sigma_i \sigma_j$ represent the estimated covariance of all corresponding projects $i, j = 1 \dots n$. This adaption makes possible a more accurate and holistic consideration of IT project dependencies. Based on this adaption, the equation for the modified α-centrality used in this paper is as follows:

$$x = (\boldsymbol{I} - \alpha * \boldsymbol{A}^T)^{-1} \circ \boldsymbol{E} \tag{6}$$

In this equation, the mathematical operator $\circ$ signifies an element-wise multiplication of the adjacency matrix $\boldsymbol{A}$, which contains the elements $\tilde{\rho}_{ij}$, and the exogenous matrix $\boldsymbol{E}$, which contains the covariances $\sigma_i\sigma_j$. The result of this multiplication is an IT portfolio risk term $\Sigma\Sigma\ \sigma_i\sigma_j\tilde{\rho}_{ij}$ that is comparable to the one introduced by Beer et al. (2013) but accounts for the specific characteristics of IT portfolio dependencies. We can thus calculate an integrated and adequately risk-adjusted IT portfolio value.

Evaluation

The evaluation of approaches for IT portfolio quantification is quite difficult because it is impossible to determine the "right" solution for an IT portfolio, which is based on several expert estimations and assumptions in each real-world case. Consequently, it is difficult to judge whether the result of an IT portfolio quantitation approach is right or wrong. It is rather a matter of how accurate or how plausible it seems. Since the approach of Beer et al. (2013) reflects an integrated approach of several well-established methods and approaches that themselves have often-times been evaluated and applied in practice and literature, we consider it an approved approach of suitable relevance and quality to serve as a benchmark for our evaluation purpose. To do justice to the Design Science Research principles, we evaluate our artifact regarding *quality, utility* and *efficacy* based on a comparison to the approach of Beer et al. (2013), henceforth referred to as benchmark approach. Therefore, we compute a simulation, which according to Hevner et al. (2004) is an established evaluation method in Design Science Research. We furthermore demonstrate the practicability of our artifact by providing an application example.

Simulation-based evaluation

Our evaluation procedure was as follows: For an exemplary IT portfolio, we calculated the IT portfolio value using our approach, which considers the systemic risk of IT portfolios based on their characteristic dependency structures. We also calculated the values for the exemplary IT portfolio based on the benchmark approach and compared the results of the two methods. Like previously explained, this approach reflects an integrated approach of several well-established methods and is therefore used as a benchmark for the purpose of this evaluation.

Since we were not yet able to gather real-world data for the evaluation presented below, we interviewed some experts to define approximate ranges for the input data based on their estimates. Table 1 presents an overview of the input data gained and used for the simulation. The experts estimated values for a project's expected net present value (which is based on the discounted cash flows of the projects) and standard deviation, for small IT projects such as updates of existing applications or mobile application development projects. They furthermore estimated the risk aversion variable γ. To investigate the effects of considering different levels of network dependencies on the IT portfolio values, we chose three different values of α—low (almost ignoring the underlying IT portfolio dependencies), medium (considering half of the effect of underlying IT portfolio dependencies), and high (full consideration of the underlying IT portfolio dependencies).

We simulated three different IT project networks with three different connectivity degrees—low, medium, and high. We define the connectivity degree as the number of edges in the IT project network divided by the maximum possible number of edges. By increasing the number of edges, the connectivity of the IT project network, or rather the dependency of the IT portfolio, increases. However, it should be noted that the connectivity degree in an IT project network will never be 100%, as not all projects in an IT portfolio will be likewise dependent on each other. In our simulation, the IT portfolios consisted of 20 projects, which resulted in a maximum number of 190 ($\frac{n*(n-1)}{2}$) edges in the network. The simulated IT project networks have 20, 30, and 50 edges, which result in connectivity degrees of 11%, 16%, and 26%. For each edge between a project i and j within a specific IT project network, we use randomly generated weights $w_{ij} \in [0,1]$ to represent the strength of the underlying dependencies between projects i and j. As previously mentioned, we compared the results of our approach with the results of the benchmark approach. Therefore, as w_{ij} can be considered equivalent to the pseudo correlation values ρ_{ij} of equation (1), we used the simulated values of w_{ij} for ρ_{ij}.

As previously explained, the parameter α determines the trade-off between exogenous and endogenous factors in the α-centrality calculation. To investigate the coherence between α and the results of our approach, we simulated three different scenarios for low, medium, and high values of α. Because $0 < \alpha < \lambda_1^{-1}$, the minimum value is close to zero and the maximum value is close to the maximum eigenvector of λ_1^{-1}.

Table 1. Simulation Input Data

	Range	Distribution
Expected net present value of each project (μ)	10,000 – 100,000	equal
Standard deviation of each project (σ)	0 – 10% of project's net present value	equal
Parameter of risk aversion (γ)	$5 \cdot 10^{-15} - 15 \cdot 10^{-15}$	equal
Correlations (ρ) for projects = Weight of the edge (w)	0 – 100%	equal
Parameter (α) for relative importance of endogenous versus exogenous factors	$0.05 * \lambda_1^{-1}, 0.5 * \lambda_1^{-1}, 0.95 * \lambda_1^{-1}$	low, medium, high
Number of projects	n	constant
Connectivity degree of the portfolio	low, medium, high	

Based on the input data summarized in Table 1, we generated 500 different IT portfolios. Table 2 presents the average results for the portfolio's value, based on the simulation for each chosen level of α and each connectivity degree.

Table 2. Average IT Portfolio's Value

Results of Φ for	IT Portfolio's Connectivity Degree		
	Low	Medium	High
Markowitz-based	1,065,436.82	1,058,239.24	1,042,966.11
$\alpha =$ low	1,079,836.90	1,079,852.78	1,079,817.76
$\alpha =$ medium	1,070,429.90	1,069,584.65	1,068,454.78
$\alpha =$ high	945,735.44	890,242.78	860,942.10

We performed the simulation several times and found that the results were reproducible. For a more convenient comparison of the results of our approach with the results of the benchmark approach, we provide the results of the evaluation in the following figures. Figure 5 presents the average results of our approach for three different values of α ($\Phi_1^*, \Phi_2^*, \Phi_3^*$). Figure 6 presents the average results of our simulation for three different IT portfolios with low, medium, and high connectivity degrees. For both figures, the vertical axis displays the risk-adjusted portfolio values derived using either the benchmark approach of Beer et al. (2013) (cf. equation (1)) or our approach (cf. equation (2)).

The results shown in Figure 5 indicate that increasing α, which implies a higher consideration of the underlying IT portfolio dependencies, leads to a lower risk-adjusted value of the IT portfolio. This shows the high impact potential of dependencies within the IT portfolio on the respective risk-adjusted portfolio value. Moreover, the results indicate that more interdependent IT portfolios are increasingly prone to systemic risk and thus have smaller risk-adjusted IT portfolio values. For low and medium values of α, the results of our approach differ from the results of the benchmark approach by between 0.5% and 3.4%. The risk of transitive dependencies seems to be comparably low for this parametrization. This, however, is quite plausible, as for low and medium values of α, the portfolio's dependence structure, represented by the weights w_{ij} of the connections, is almost neglected. In contrast, for a value of α which is close to the upper boundary λ_1^{-1}, the portfolio's dependence structure is considered to be more important, and the simulation shows significant differences between the two different IT portfolio evaluation approaches with respect to the consideration of characteristic dependency structures.

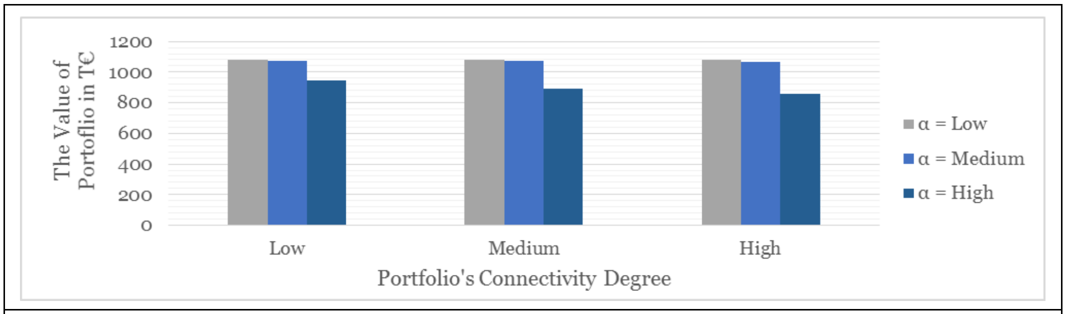

Figure 5. Evaluation of the Results

Depending on the connectivity of the specific IT portfolio, the benchmark approach leads to an overestimation of the risk-adjusted portfolio value by between approximately 11% and 17%, based on a high value of α. For connectivity degrees of 11%, 16%, and 26%, which are referred to as low, medium and high, this coherence is illustrated in Figure 6.

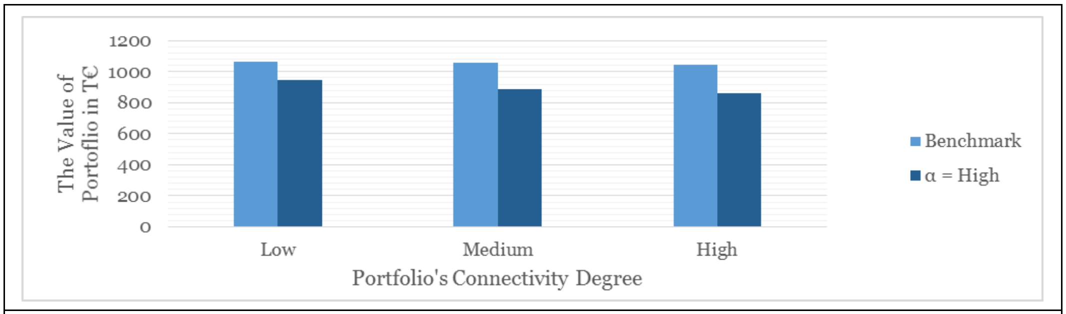

Figure 6. Evaluation of the Results

Based on our simulation results, we conclude that for IT portfolios with low degrees of connectivity, the risk-adjusted portfolio value determined using our approach and that determined using the benchmark approach are relatively similar, differing by approximately 11%. This implies that the risks of overestimation and underestimation in IT portfolios with lower connectivity degrees are comparably low. For IT portfolios with moderate (16%) degrees of connectivity, the difference is approximately 16%, and for portfolios with high (26%) degrees of connectivity, the difference is approximately 18%. We conclude that the probability of underestimating or overestimating the risk-adjusted IT portfolio value increases with the number and strength of directly and indirectly dependent projects in an IT portfolio.

Application example

The following example illustrates the applicability of our approach using data that has been shown to be obtainable in practice by Beer et al. (2013). We consider the exemplary IT portfolio shown in Figure 4 and calculate the IT portfolio's values using our method and the one of Beer et al. (2013) to illustrate the effects of integrating different types of dependencies and modeling IT portfolios from a network perspective. We defined the range of the IT project's expected values to be 266,700 € to 626,700 €, the standard deviations to be 20%, and the value of risk aversion γ to be 0.000031, based on the parameters given by Beer et al. (2013). Since we examined the exemplary IT portfolio of Figure 4, we generated random values for the weights (w) of the edges according to the ranges given in Table 1. However, as it has been shown by Beer et al. (2013), such weights representing the strength of dependencies between two projects of the IT portfolio can easily be determined based on expert estimations. We used the same input parameters for both methods. The results for the parameters of equations (1) and (2) are as follows: $\sum_i \mu_i$ is 3,060,759.70, $\gamma \cdot \sum_i \sigma_i^2$ is 461,647.02, $\gamma \cdot \sum_i \sum_{j \neq i} \sigma_i \sigma_j \rho_{ij}$ is 189,480.40, and $\gamma \cdot \sum_i \sum_{j \neq i} \sigma_i \sigma_j \tilde{\rho}_{ij}$ for low, medium, and high α values are 11,052.68, 201,348.68, and 3,870,817.02. The IT portfolio values obtained using Beer et al. (2013) and our method for low, medium, and high α values are as follows: 2,409,632.28 €, 2,588,060.00 €, 2,397,763.99 €, and -1,271,704.34 €. The result of this application example indicates similar conclusions like the results of the simulation. In comparison to Beer et al. (2013), our approach leads to higher project values for low α values, since in this case almost all dependencies and corresponding risks of the IT portfolio are neglected. However, the results also show that in cases of high α values (as in our simulated example with the maximum α), our approach, in comparison, provides lower IT portfolio values that might even be negative due to the inherent risk of direct and indirect dependencies. Such values indicate IT portfolios that can cause financial losses for an organization. Such potential losses would probably be overlooked by the application of methods that do not appropriately consider the dependence structure of an IT portfolio.

Conclusion, Limitations, and Outlook

Our novel approach integrates various types of direct and indirect (transitive) dependencies between IT projects and thus enables holistic, quantitative, value-based IT portfolio evaluation in a feasible way. By considering IT portfolios as IT project networks and using α-centrality to investigate and evaluate underlying dependency structures, we addressed the major challenge stated by Benaroch and Kauffmann (1999) and adapted a model from another academic discipline to IS research. We combined α-centrality with an established and thoroughly evaluated, integrated approach for IT project and portfolio evaluation provided by Beer et al. (2013) to derive a comprehensive approach to value-based IT portfolio evaluation that appropriately considers risks emerging from characteristic dependency structures, as well as the costs and benefits of IT portfolios. This approach was developed and evaluated in line with Design Science Research principles. By means of simulation, we examined the quality and efficacy of our approach and compared it to the approach of Beer et al. (2013), which is based on the well-established methods from decision theory. The results of our simulation indicate that for low connectivity of the IT project network, which reflects a low number of dependencies in the corresponding IT portfolio, the results of our approach are comparable with the result of the one of Beer et al. (2013). This confirms the validity of the results of our approach. For IT portfolios with a high number of dependencies, our approach yields different results than the other approach of Beer et al. (2013) that is based on Markowitz's portfolio theory. This, however, seems quite plausible because the Markowitz-based approach does not consider systemic risks associated with transitive dependencies and consequently overestimates the overall IT portfolio value. We moreover illustrated an application example for further evaluate and demonstrate the feasibility and utility of the approach.

Nevertheless, our approach has some limitations. Because it is a deductive mathematical approach, we had to make a few simplifying assumptions and apply some constraints that are not entirely realistic. For instance, we defined an IT project as being assigned to one specific period in time. In reality, there may be IT projects which, even if subdivided into smaller subprojects, have to be assigned to more than one period of time. Our assumption of normally distributed cash flows might also be unrealistic in some cases, but it is a common assumption in IT portfolio management (cf. Fridgen and Müller 2011; Fridgen et al. 2015; Wehrmann and Zimmermann 2005; Wehrmann et al. 2006; Zimmermann et al. 2008). However, the more cash flows are considered within the evaluation of an IT portfolio, the better the central limit theorem and variations thereof apply, which supports the normal distribution assumption. Another assumption of our approach is that the coherence between the duration of an IT project and its assigned assets is linear. Although this assumption might not be realistic for each type of asset, it seems plausible for at least the most important intra-temporal dependencies, and we considered it to be appropriate for this first step towards an integrated value-based IT portfolio evaluation. Finally, the validity and contribution of our approach has only been demonstrated by means of simulation. For further evaluation and improvement of the method, it should be applied to real-world scenarios. This will be addressed in future research. Moreover, future research should investigate whether the integration of different risk measures can yield even more plausible results regarding the consideration of risk associated with direct and indirect dependencies or whether the existing limitations can be reduced. Furthermore, an extension of the integrated ex ante evaluation of IT portfolios to integrated ex nunc (continual) IT portfolio control and management may be of interest in holistic IT portfolio management.

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