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Systemic Risk in IT Portfolios – An Integrated Quantification Approach

by

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Abstract

Recent trends in digitalization combined with continuous innovation pressure lead to an increasing number of IT project, which nowadays are accomplished within huge IT project portfolios. Even though numerous IT project and portfolio evaluation and planning approaches have been developed and applied in companies all over the world, about 25% of IT projects still fail, which may result in a global value destruction of approximately 900 billion USD. With one main reason been detected in the lack of transparency regarding dependencies within IT portfolios, this paper draws on graph theory to provide a rigor consideration of the systemic risk that is based on different kinds of direct and indirect dependencies within IT portfolios. Based on this assessment, it provides an integrated novel, and quantitative approach for IT portfolio evaluation that strives to mitigate IT project failures, as it helps decision makers to evaluate their IT portfolios more adequately.

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

Introduction

New trends like digitalization intensify the anyway high importance of Information Technology (IT) to companies all over the world. Additionally, recent technological developments and associated changes in customer expectations force companies to continuously come up with innovative ideas and creative solutions (Nguyen and Mutum 2012), which can be translated in a vast increase of IT projects to fulfill these demands. As a consequence, more and more IT projects are split up into several standalone but interrelated IT solutions with customer impact, to satisfy this continuous demand for innovation. To handle this development and the resulting increase of IT project portfolio complexity, a holistic approach for the valuation of IT project portfolios, which are henceforth simply referred to as IT portfolios, is crucial. Although there are already a number of approaches, the investments in planning techniques for IT projects and IT portfolios still increase. (Gartner 2014). Nevertheless, there is still an alarming high number of failed IT projects. In this context, Flyvbjerg and Budzier (2011) contend that around 16% of IT projects cause an average budget deficit of about 200%. Moreover, there are project failure rates of above 25% (Mieritz 2012), which may result in a global value destruction of approximately 900 billion USD (Gartner 2013). Consequently, recent studies show that existing methods for IT project and IT portfolio evaluation might not be sufficient (Flyvbjerg and Budzier 2011; Radar Group 2012).

Usually, IT projects are planned and implemented within aggregated and quite extensive portfolios of several different IT projects, like mobile app development projects, database restructuring projects, and big software development projects for business systems applications. Therefore, they incorporate high-order dependencies in contrast to projects that are accomplished in isolation or pairwise (Graves et al. 2003). Consequently, one major reason for project failures may be the inappropriate reflection and consideration of dependencies regarding shared assets between IT projects (CA Research 2008). This fact is also supported by a questionnaire done by the Radar Group, surveying 560 IT decision makers in Scandinavia, which concludes that one reason for IT project failure is a lack of transparency regarding dependencies (Radar Group 2012). Furthermore, the management of those dependencies could most probably also help to reduce overall IT project costs and increase the achieved benefits of IT projects (Santhanam and Kyparisis 1996). However, many existing methods do neither consider dependencies of IT portfolios nor their associated risk. Even if there are some approaches (cf. Beer et al. 2013; Kundisch and Meier 2011; Lee and Kim 2001; Wehrmann et al. 2006), which do consider dependencies within their IT project or IT portfolio evaluation procedure, they do not consider the specific characteristics of IT portfolio dependencies. Different kinds of dependencies or the prevalence of transitive dependencies are almost consistently neglected in existing IT portfolio evaluation methods. Furthermore, some approaches which do consider dependencies of IT project portfolios in a more elaborate way, lack the quantitative evaluation of them and are therefore mostly not regarded as a reasonable decision-support for IT portfolio managers (Müller et al 2015). Generally, most approaches also lack the 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 of IT projects.

Like already stated by Benaroch and Kauffmann (1999), "a major challenge for IS research lies in making models and theories that were developed in other academic disciplines usable in IS research and practice". Since classical methods of project and portfolio management are considered insufficient for the specific characteristics of IT portfolios, we draw on a concept from sociological research based on graph theory. By considering IT portfolios as IT project networks, where projects are reflected by nodes and dependencies between them by arcs, we present a fresh and novel approach that combines concepts from graph theory with classical portfolio theory. Thus, we are able to develop an integrated approach of value-based IT portfolio evaluation that considers costs, benefits, risks and different kinds of dependencies in a thoroughly, quantitative and feasible way. Especially the appropriate consideration of different kinds of dependencies and in particular of transitive dependencies in IT portfolios is supposed to be a main contribution of this paper, since they have been identified as an important reason for IT project failures but have not yet been sufficiently considered in existing research to the best of our knowledge. Therefore, the results should empower decision-makers to adequately consider dependencies and associated risks within their IT portfolio evaluation.

To provide a relevant and rigorous approach, we follow (Hevner et al., 2004) and (Gregor and Hevner, 2013). We develop our approach as an artifact and evaluate it considering design science guidelines. To state the relevance and the need for an integrated approach for value-based IT portfolio evaluation clearly, we draw on motivation from research and practice in section 1. Based on a structured literature review and recent state-of-the-art articles, in section 2 we explain the key terms and concepts, how they are connected, and how they are already addressed in research. In section 3 we develop our integrated approach step by step to ensure comprehensibility. To guarantee research rigor, we base our approach on existing literature and well-established methods and theories. We draw on simulation as our method of choice to evaluate our approach in section 4. Thereby we show the plausibility of our approach itself and indicate benefits in comparison to well-established theories. Section 5 concludes, shows existing limitations of the approach, and gives indications for future research.

Theoretical Background

Since decades the subjects of IT project and IT portfolio evaluation as well as an appropriate consideration of dependencies, are highly relevant topics in research and practice. Hence, it is reasonable that over the last decades an extensive amount of publications has been published in this context. 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 in this context. Thus, we first give a general overview about methods for IT project and IT portfolio evaluation. Afterwards, different kinds of dependencies are identified and elaborated, before we examine how they are currently appraised in literature. Therefore, we do a keyword (dependency, interdependency, interaction, project, portfolio, information technology, information systems, model, method, requirements, approach, quantification, assessment, IT project, evaluation, value assurance, valuation) based search of different data bases (AIS Electronic Library, EBSCOhost, EmeraldInsight, ProQuest, ScienceDirect, Wiley, Google Scholar, JStor, Springer, ACM). Although this search reveals a lot of relevant articles, we find that most of them are already condensed within most recent state-of-the-art articles. Regarding our first subtopic of IT project and IT portfolio evaluation methods, Beer et al. (2013) include an extensive literature review section within their research about an integrated project quantification method. The second subtopic of different kinds of dependencies is outline by Wolf (2015) and quite comprehensively also by Müller et al. (2015), who provide a dedicated state-of-the-art article to different kinds of dependencies and their current appraisal. Therefore, based on our keyword based search and the recently published state-of-the-art articles, we try to provide a brief, sound and especially integrated overview about existing research, which however is structured according to the three aforementioned subtopics. However, for a more detailed literature synthesis to one or all of the presented subtopics, please refer to the respective articles of Müller et al. (2015), Wolf (2015) and Beer et. al (2013).

Methods for IT Project Evaluation and IT Portfolio Evaluation

In this context it is important to notice, that the evaluation of IT portfolios generally 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 distinctly delimitate IT project and portfolio approaches, this section gives only a brief overview about important IT project and portfolio evaluation methods, without distinguishing regarding premises for the application within a project or portfolio context. There are indeed many approaches and methods in literature which deal with IT project and portfolio evaluation. However integrated evaluation approaches that should consider benefits, costs, risk, and dependencies in a quantitative and feasible manner are quite rare, even if it is stated that this is a highly relevant topic in research and practice (Müller 2015). Existing approaches oftentimes just account for qualitative factors. Although, some models also use quantitative figures for the valuation of benefits and sometimes also risks, but unfortunately not on a monetary basis. In the following, we shortly present some existing approaches for IT project and portfolio evaluation. Since the scope of this paper is specifically on quantitative methods for IT project and portfolio evaluation, we focused on these kinds of approaches, although we are aware that lots of publications are heading in the direction of a more general evaluation that additionally accounts for qualitative factors.

A frequently used possibility 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 of a specific IT project. Subsequently, the resulting scores are aggregated to an overall value that enables the comparison of different alternatives. The Balanced Scorecard by Van Grembergen and De Haes (2005) is kind of a scoring model, too. Firstly, the relations of cause and effect of qualitative and quantitative key figures are described to identify two general types of key figures: performance drivers and output figures. Based on the degree of target achievement of each key figure, the project will be evaluated. The so-called WARS-Model (Ott 1993) has the ability to crudely estimate benefits and costs by subdivided them into three categories according to their tangibility. The risk aversion of decision-makers is kind of taken into account by different risk stages for optimistic or pessimistic decision-makers. A more quantitative way of IT project evaluation was presented by Schumann (1993), whose approach is based on functional chains. By focusing on their effects, benefits can be depicted as monetary values. 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 functional they derive a monetary, risk adjusted project value. It also is proved as a feasible approach by business experts, but have not been applied to IT portfolio evaluation. Like the one of Beer et al. (2013) there are many approaches for IT project and portfolio evaluation that refer to or are based on the well-known Markowitz portfolio theory (1952) as this seems to be an adequate means to derive a risk adjusted value based on a μ/σ-decision rule.

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

Different Kinds of Dependencies

As mentioned before, there are different kinds of dependencies between IT projects within IT portfolios. This fact is also reflected in respective literature. We found, that some articles just mention certain kinds of dependencies, while others try to integrate and structure these kinds of dependencies in specific frameworks. Most articles (e.g. Lee and Kim (2001); Santhanam and Kyparisis (1996); Tillquist et al. (2004) or Zuluaga et al. (2007)) report about resource dependencies, technical dependencies or 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 ones 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 existing literature, but in general, two major categories can be differentiated: technical dependencies can either arise from two projects competing for technical resources like depicted by Wehrmann et al. (2006) or, otherwise, 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 simultaneously being implemented with another. Examples for such synergies could be databases, which have been built for a certain project, and can likewise be used for other projects. Other examples are accumulated expert knowledge, which is relevant for more than one project, or 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 dependencies of different projects that are accounted to the same period in time. They are supposed to encompass structural dependencies and resource dependencies. (Wehrmann et al. 2006) Looking at 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). Generally, there is a common understanding in literature about causes of resource dependencies in IT projects. They are supposed to arise due to the sharing of scarce resources like personnel, hardware (servers) or software (database logics) resources (Graves and Ringuest 2003; Santhanam and Kyparisis 1996). Structural dependencies can be divided in the subcategories 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 do apply the same IT-functionalities (Wehrmann et al. 2006).

Inter-temporal dependencies in contrast refer to dependencies of different projects that are accounted to different periods in time. Thus, inter-temporal dependencies describe a coherence where a succeeding project is based on a preceding one. They can be distinguished in 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). The majority of approaches however focuses on out-put-resource based dependencies, whereas just output dependencies without the resource context are barely included.

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

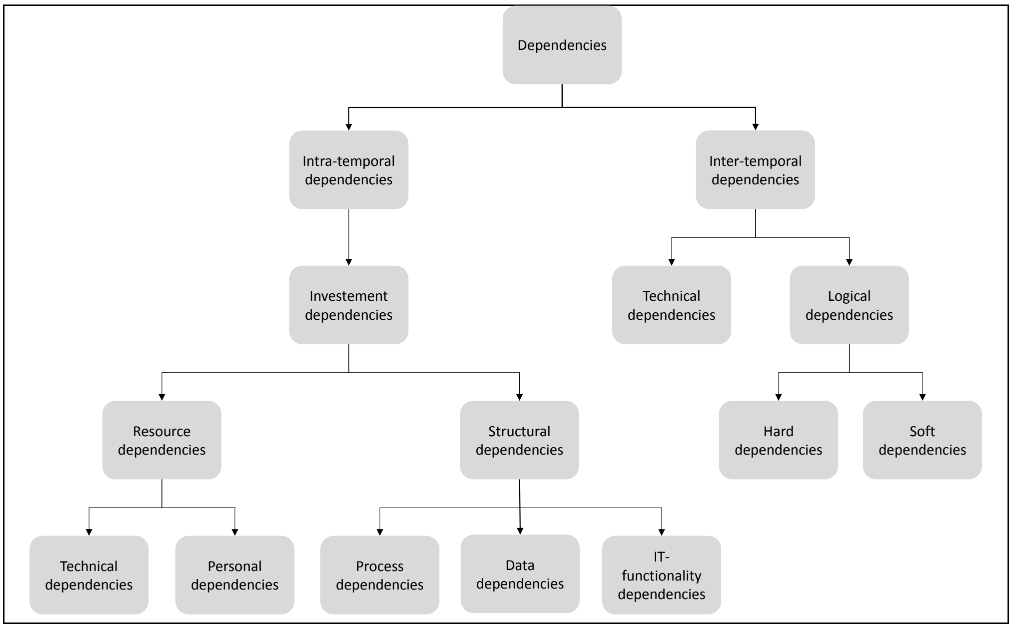

Figure 1. Dependencies in IT portfolio

Methods for Consideration of Dependencies

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

Intra-temporal dependencies

There are different approaches to account for intra-temporal dependencies of IT projects and IT portfolios. One possibility is to integrate them as auxiliary conditions in an optimization model (Kundisch and Meier 2011; Lee and Kim 2001; Santhanam and Kyparisi 1996). Another way to consider dependencies, which for instance was used by (Beer et al. 2013; Butler et al. 1999; Wehrmann et al. 2006) is to draw on portfolio theory of Markowitz (1952) to determine a risk and return optimized IT portfolio by normalized covariances of the corresponding IT projects. A modified discounted cash flow approach was presented by Verhoef, which considers dependencies implicitly while focusing on cost and time risks within the interest rate (2002). However, many of the presented methods partially fall short due to their underlying financial restrictions (Zimmermann et al.2012) or because they oftentimes due not consider the dependence structure of the whole portfolio but only focus on dependencies between two specific projects. Furthermore, a wide number of publications concerning intra-temporal dependencies, particularly from problem solving domains like Operations Research, do not only focus on the ex-ante evaluation but rather provide procedures to continuously consider dependencies during the portfolio planning processes. Thus, the contributions of these papers are methods, models, or algorithms that rather aim at solving specific capacity problems in the context of intra-temporal dependencies instead of 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 approaches, which however stem from options theory in the financial sector. In particular, find several methods in literature that are based on the Black-Scholes model while only some use binomial trees to picture inter-temporal dependencies. (cf. Bardhan et al. 2004; Benaroch and Kauffmann 1999; Dos Santos 1991; Taudes et al. 2000). Although, as once again both procedures originally were 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 appropriate applicability to inter-temporal dependencies in the context of IT portfolios is doubtful. For a more detailed discussion whether real option approaches are applicable in the IT portfolio context, please refer to Diepold et al. (2009) and Ullrich (2013), who provide a detailed investigation about the transferability of these methods for considering dependencies in IT project and IT portfolio evaluation.

There are also first attempts to integrate the two kinds 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 kinds of dependencies in IT portfolios and their current appraisal, we can conclude that different kinds of dependencies are almost always considered isolated from one another. However, since in reality different kinds of dependencies are interconnected and they can be found in every IT portfolio, they have to be considered in a holistic way, which is not done by any approach so far (cf. Müller et al. 2015). Moreover we found, that none of the existent IT portfolio evaluation and management techniques explicitly considers transitive dependencies between IT projects within IT portfolios. However, an assessment of these transitive dependencies is essential for an appropriate risk assessment and value-based evaluation in these network-like structures. Therefore, none of the investigated approaches can be considered completely appropriate regarding an integrated value-based evaluation of IT portfolios that accounts for their characteristic inherent dependency structures.

Modeling Procedure, Assumptions, and Requirements

In this section we develop an integrated, quantitative approach for a holistic IT portfolio evaluation, which not only considers different kinds of dependencies but also accounts for transitive dependencies. Therefore, we first of all introduce an integrated approach that generally is capable to account for cost, benefits, risk and dependencies of IT projects in a portfolio context. Subsequently, we enhance this approach to likewise account for intra- and inter-temporal dependencies within the IT portfolio evaluation. We introduce a procedure to quantify the strength of intra- and inter-temporal dependencies based on a common underlying and aggregate them to 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 on IT Project Evaluation

For a quantitative calculation of the IT portfolio, we draw on the established perspective of Markowitz (Markowitz 1952). More specifically, we adapt and modify the integrated approach of Beer et al. (2013), who use the preference function to determine a risk adjusted IT project value. This function is an established method of decision theory (Bernoulli 1738; Bernoulli 1954; Markowitz 1952; von Neumann and Morgenstern 1947) and has already been used in quite a number of IT project-related articles (cf. Bardhan et al. 2004; Fogelström et al. 2010; Fridgen and Müller 2011; Hanink 1985; Zimmermann et al. 2008). Thus, Beer et al. (2013) determine a risk-adjusted IT project value Φ, based on the overall costs C of the complete IT project and the aggregated sum of all projects` expected benefits $\Sigma\ \mu_i$. Similarly to Markowitz, dependencies are considered by a Bravais-Pearson correlation coefficient ρ_{ij} and offset within one term for risk adjustment $\Sigma\ \Sigma\ \sigma_i \sigma_j \rho_{ij}$. Furthermore, to account for the level of risk aversion of the decision maker, this term of risk adjustment is weighted by a risk aversion parameter γ.

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

This approach is used for the evaluation of IT projects with a particular focus to benefits management so far, but since it is based on Markowitz portfolio theory, it can easily be adapted for the evaluation of IT portfolios. In contrast to Beer et al. (2013) we however take a cash flow based perspective, like similarly done by Fridgen et al. (2015).

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

Although normally distributed project cash flows might not picture reality in every case, they are a common assumption in IT portfolio management (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 $i = 1 \ldots n$ of the IT portfolio. Consequently, μ_i represents the expected value of the IT project and σ_i its corresponding risk.

However, while Beer et al. (2013) and Fridgen et al. (2015) consider dependencies by a correlation coefficient between every pair of their underlying investigation objects, and derive an overall term for risk adjustment, we in contrast distinguish between an IT project risk term $\Sigma\ \sigma_i^2$, referring to risk related to each particular IT project itself and an IT portfolio risk term $\Sigma\Sigma\ \sigma_i \sigma_j \tilde{\rho}_{ij}$, referring to the systemic risk originating form inherent direct and indirect dependencies between IT projects of the IT portfolio.

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

Since we strive to depict both, direct (pairwise) and indirect dependencies, we refrain from assuming a Bravais-Pearson correlation coefficient ρ_{ij} between every pair of IT projects but draw on alpha centrality to determine a corresponding IT portfolio risk term $\Sigma\Sigma\ \sigma_i \sigma_j \tilde{\rho}_{ij}$ that likewise accounts for direct and transitive dependencies of the IT portfolio. However, before we are able to do so, we need to assess and aggregate the different kinds of dependencies prevailing between two different IT projects of the IT portfolio to a single dependency value and determine its quantitative extent.

Assessing different kinds of dependencies

As stated above, within an IT portfolio there are different kinds of dependencies. We stick to the distinction of Wehrmann et al. (2006) between intra- and inter-temporal dependencies. In 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 data base). Therefore, we henceforth use the word asset to address either resources or infrastructures, which are planned for an IT project. Moreover, each IT project can be separated to many interdependent activities. Accordingly, also existing dependencies between two IT projects can be considered as the result of dependencies on a more granular level. To facilitate this circumstances, we do not distinguish between different levels of granularity and consider an IT project to be the most granular level that cannot be divided into a further distinctive category of activities. Furthermore, we assume every IT project to be accountable to one specific period of time t, i.e. start and end date of the project are within the same period. In reality, IT projects often take place over several years, though. Consequently, we assume that these IT projects can be subdivided into smaller ones that can be accounted to one specific period of time. An IT portfolio usually has a specific planning horizon and encompasses IT projects in many of the covered periods $t = 1 \ldots T$. There can also be $1\ to\ m$ IT projects within the same period of time, since there might be more than one IT project going on at the same time even in small companies.

There are two different perspectives on how assets are shared between IT projects: The asset pooling 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 between $[0\% \ldots 100\%]$. Therefore, in each point in time the sum of the shares of an IT project on the asset cannot exceed 100%. If asset a_1 is shared between IT projects i, j, and k and the shares of the IT projects on 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. To ease the comprehensibility, we illustrated this coherence in Figure 2.

This perspective however seems unfavorable in case of inter-temporal dependent IT projects. Since asset pool and IT portfolio are strictly segregated, an IT project would have to be considered as an asset in order to serve as an input for 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 paper.

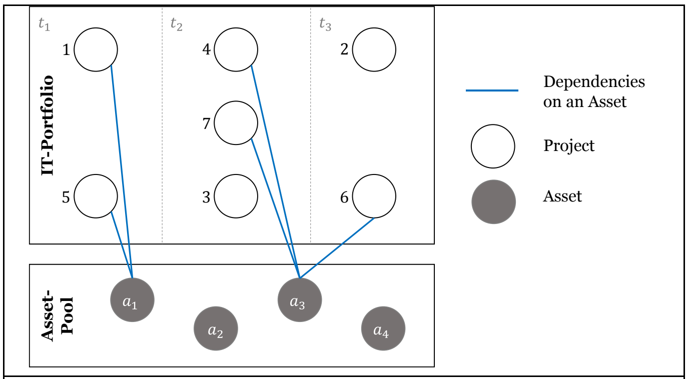

Figure 2. Asset Pooling in an Exemplary IT portfolio

In this context, the *asset accounting perspective* provides a more appropriate solution for the likewise consideration of intra- and inter-temporal dependencies. Within this perspective, assets are directly accounted to IT projects that depend upon them (cf. Figure 3). Consequently, $[1 \dots n]$ assets can be allocated to $[1 \dots n]$ IT projects with a percentage share between $[0\% \dots 100\%]$. However, also in this case the sum of shares of an IT project on an asset cannot exceed 100% at each point in time. If the asset is accounted to solely one specific IT project, there is no dependency to another IT project caused by this asset. For instance if a software developer (personnel resource) is allocated exclusively to project i, other projects are not having any dependency on project i resulting from this asset.

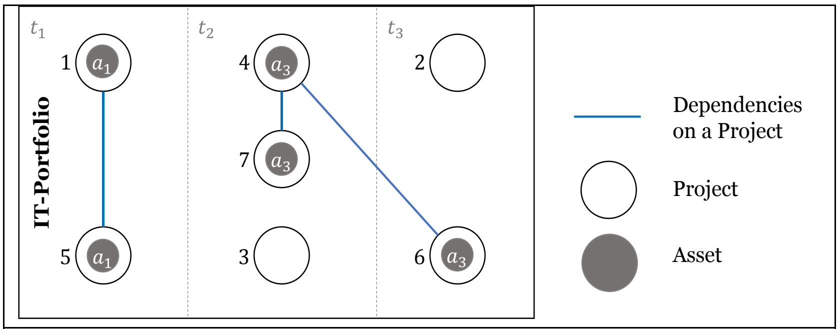

Figure 3. Asset Accounting in an Exemplary IT portfolio

Like shown in Figure 3, within 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 representing the dependency can easily be considered. However, it should be noted that an asset that is accounted to two consecutive IT projects (cf. Figure 3 between project 4 and 6) does not constitute an inter-temporal dependency. This is due to our assumption that every IT project is accountable to one specific period of time. Therefore, if an asset is accounted to two projects that take place at different points in time, it does not cause any dependency as the precedent project has finished using the asset before the succeeding one starts to use it.

Besides the dependency caused by sharing a specific asset between IT projects that previously has been outlined, assets generally are able to cause a different kind of dependency: The dependency regarding the availability of the asset itself. Each kind of asset has an inherent risk of failure, which is independent of the fact whether it is shared between different IT projects. In the context of personnel resources, the general availability of a software developer for instance depends on its personal health. Since this kind of dependency therefore not depends on dependencies of different projects to specific assets, it is not considered within the IT portfolio risk term and thus is not included in the following examinations.

Aggregating of different kinds of dependencies to a single value

Since we likewise want to consider inter- and intra-temporal dependencies, we need to aggregate them to 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 as 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. Dependencies (inter-/ intra-temporal) between IT project $i, j =$

1 … n are represented by a directed edge between these IT projects. Inter-temporal dependencies are represented with a directed edge pointing from the dependent IT project to the IT project it depends upon. Logically, when IT project i is inter-temporally dependent on IT project j, IT project j cannot be inter-temporally dependent on IT project i. Intra-temporal dependent IT projects are sharing an asset within the same period in time. Hence, as these IT projects are affected contemporarily, 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 to represent the strength of the dependency between the aligned IT projects.

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

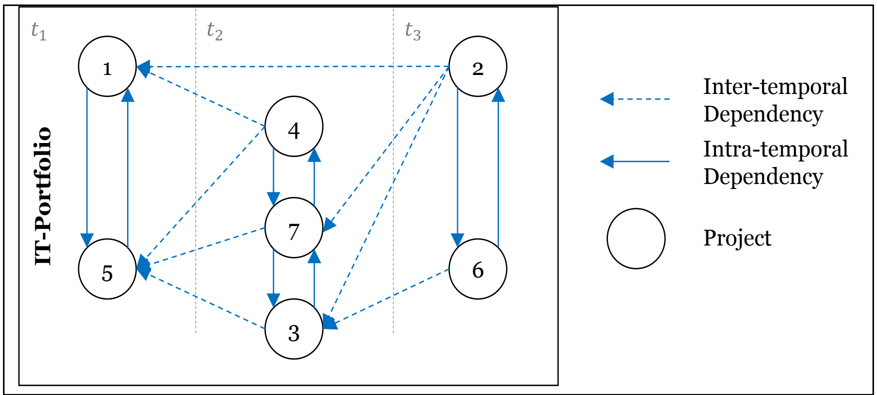

Figure 4. Exemplary IT portfolio

In order to aggregate intra- and inter-temporal dependencies to a single value, we quantify the strength of these dependencies based on the same underlying. We identify 'time' to be the common factor that enables a quantitative determination of inter- and intra-temporal dependencies. More specifically, we draw on the relative time lag that a particular IT project can possibly cause to the other projects that depend on this particular one. In the following, we consecutively depict the quantification of intra- and inter-temporal dependencies.

Intra-temporal dependencies

In case of intra-temporal dependencies, the relative time lag refers to the time that an IT project - in case 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 kinds 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 a 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 for a particular IT project and on the size of the project, we denote it as a relative value of the project size. Therefore we consider each IT project $i = 1,..,n$ to have a size S^{p_i}, which is usually measured in a time-related unit like for instance Full Time Equivalent (FTE). For reasons of comprehensibility, we however consider project size to represent the overall duration for the implementation of an IT project in working hours. Yet, based on the average working hours of a specific company, this value can easily be converted into FTE. Using the projects size, we are able to determine the projects 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 picture reality for each kind of asset, it seems plausible for at least the most important intra-temporal dependencies and it is easy to grasp. Therefore, we consider it as appropriate assumption for a first step towards an aggregation and consistent quantification of different kinds of intra-temporal dependencies. Based on this assumption, we are able to quantify the intra-temporal dependencies between two different IT projects. Therefore, we calculate the mutually prolongation of project duration, resulting from the reciprocal shortfall of required assets according to the following equation:

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

Therefore, we use this equation to calculate two different scenarios, which will be related afterwards. Within the first (max-)scenario, we calculate the duration of the project in case all planed assets a_k, uncritical assets a_k^{uc} and critical assets a_k^c, of each asset category $k = 1 \dots l$ (e.g. resources and infrastructure) are available. The availability is reflected by the parameter ϑ_k with $0 \leq \vartheta_k \leq 1$, which represents the percentage of availability of the assets of a specific asset category. Consequently, in case of the first scenario, $\vartheta_k = 1$ for each asset that is assigned to the IT project. Correspondingly, in the second (min-)scenario we calculate the duration of the project in case another rival IT project is given preference regarding all critical assets a_k^c. In this case, $\vartheta_k = 0$ for all competed assets. Putting the resulting values of the two scenarios in relation, we can derive the relative prolongation of each project duration, which is caused by asset category $k = 1 \dots m$:

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

To illustrate this coherence we draw on Figure 3, where p_1 has intra-temporal dependencies to p_5, caused by a single asset category a_1. Let p_1 be a software development project with an approximate size of about 250 working hours and p_5 a smaller one with an approximate size of 150 working hours. Project p_1 requires five assets a_1 of category $k = 1$ and p_5 requires three to be accomplished according to schedule. 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 (3), we now 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 as the percentage prolongation of p_1 due to the critical asset category $k = 1$.

In case there is only one critical asset category like 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 one p_j it depends upon due to the specific asset category. However, if there are multiple critical asset categories $k = 1 \dots m$, we need to aggregate these categories in order to derive a single value for intra-temporal dependencies. Therefore, in this case w_{ij} equals $\sum_{k=1}^{l} \Delta D_k^{p_i}$. This can possibly lead to values $w_{ij} > 1$, though. Since $w_{ij} = 1$ refers to the maximum dependency of 100%, we set $w_{ij} = 1$ for each aggregated value $w_{ij} > 1$.

Inter-temporal dependencies

Inter-temporal dependency are considered over the whole planning horizon of the IT portfolio. If two projects are inter-temporal dependent, they are accounted to different points in time, which 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 point as follows:

- Finish-to-start (FS): The start of the successor project depends upon the completion of the predecessor project.
- Finish-to-finish (FF): The completion of the successor project depends on the completion of the predecessor project.
- Start-to-start (SS): The successor and predecessor project should start at the same time and hence are allocated to the same period of time. As this case there is no dependency between the successor and predecessor project, it is not considered 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. It implies the predecessor project to be started before the successor project can be finish. Since this case does not reflect any kind of dependencies between the results of the predecessor project and the successor project, but is mainly an issue for planning purposes and is not considered as inter-temporal dependency in the sense of this paper.

Consequently, we distinguish only two kinds of inter-temporal dependencies within our paper: FS and FF dependencies that refer to different projects taking place at different points in time. Like in case of intra-temporal, we draw on relative time lag that depicts the prolongation of the project implementation time due to inter-temporal dependencies. In particular, we assess inter-temporal dependencies by calculating a relative prolongation of the project implementation of the succeeding project p_2 based on a delay of a preceding project p_1 (cf. Figure 4). In case there is a 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 a 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 a partial completion as well, we can determine the strength of this kind of dependency according to the percentage of the predecessor project that has to be accomplished before the successor project can be finished. Consequently, if 60% of p_1 need to be accomplished before p_2 can be finished, 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

Like mentioned before, we strive to determine an IT portfolio risk term $\Sigma\Sigma\ \sigma_i\sigma_j\tilde{\rho}_{ij}$ that likewise accounts for direct and transitive dependencies of an IT portfolio. Therefore, we stick to the idea presented by Wolf (2015), considering an IT portfolio as IT project network where each node represents a project and each arc a dependency. We consequently use alpha centrality to assess the networks dependence structure and the corresponding inherent systemic risk. Alpha centrality "does not only account for direct dependencies like the number of directly dependent projects, but also for indirect or transitive dependencies. Thereby, it considers that more interconnected and therefore critical projects contribute stronger to the criticality of the ones they are dependent on than projects that are less critical" (Wolf 2015). In the following, we briefly introduce the elements of alpha centrality and illustrate how it can be adapted to derive an IT portfolio risk term that can be used within the integrated quantification approach illustrated in (2). For a more elaborate explanation of whether alpha centrality can be used in an IT project context, please refer to Wolf (2015). Alpha centrality can be calculated according to the following equation:

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

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 strength 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 object (e.g. IT projects) based on expert judgements. Therefore, we henceforth considered w_{ij} as $\tilde{\rho}_{ij}$ of our IT portfolio risk term $\Sigma\Sigma\ \sigma_i\sigma_j\tilde{\rho}_{ij}$. The remainder elements of (5) are the identity matrix $\boldsymbol{I}$ and the scalar $\alpha > 0$. The latter one is an arbitrary ratio between the endogenous status of nodes (projects), which is calculated based on the network (dependency) structure, and the exogenous status of nodes, which can arbitrarily be assigned based on the vector $\boldsymbol{e}$. The parameter α can adopt values in the range of $0 < \alpha < \lambda_1^{-1}$, whereas λ_1^{-1} is the maximum value of the eigenvector of the adjacency matrix $\boldsymbol{A}$. Most researchers choose the value of α close to the maximum value of λ_1^{-1} (Newman, 2010), as in this case this choice makes the maximum consideration of the endogenous characteristic or rather the network or dependency structure. The exogenous status represented by the vector $\boldsymbol{e}$ generally provides the possibility to assign a value to each node of the network, which is independent of the actual network structure that is depicted by the adjacency matrix $\boldsymbol{A}$. Within an IT portfolio context, this exogenous status might for instance be the risk or the size of a project. Considering the exogenous status to rather be reflected by a matrix $\boldsymbol{E}$ whose elements $\sigma_i\sigma_j$ represent the covariance (not normalized) of the corresponding projects $i, j = 1 \dots n$ instead of a vector $\boldsymbol{e}$, we however adapt alpha centrality to determine a risk measure for the respective IT portfolio. Based on this adaption, the equation for the modified alpha centrality used in this paper is a follows:

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

Within this equation, the mathematical operator '∘' describes an element-wise multiplication of the adjacency matrix $\boldsymbol{A}$, containing the elements $\tilde{\rho}_{ij}$, and the exogenous matrix $\boldsymbol{E}$, containing the covariances $\sigma_i\sigma_j$. The result of this procedure is an IT portfolio risk term $\Sigma\Sigma\ \sigma_i\sigma_j\tilde{\rho}_{ij}$, which is comparable to the one introduces by Beer et al. (2013), but accounts for the specific characteristics of IT portfolio dependencies. Based on (2) we thus can calculate an integrated and adequately risk adjusted IT portfolio value.

Evaluation

The evaluation of approaches for IT portfolio quantification is quite difficult, since it is impossible to determine a 'right' solution for an IT portfolio, which is based on several expert estimations and assumptions in each real world case. Consequently, it is hard to judge whether a result of an IT portfolio quantitation approach is right or wrong. It is rather a matter of how accurate or how plausible it seems. Consequently, we do a simulation based evaluation of our approach, which according to the design science approach of Hevner et al. (2004), is a legitimate means for evaluation. Since we were not yet able to gather real world data, and the validity of this data would also be questionable due to the underlying expert estimations, we directly asked some experts and defined the rough ranges for the input data based on their estimation. We subsequently performed the simulation based on randomly generated values in the predefined ranges. Table 1 provides an overview of our input data for the simulation. Our evaluation procedure is as follows: For an exemplary IT portfolio, we calculate the IT portfolio value using our approach, which considers the systemic risk of IT portfolios based on their characteristic dependency structures. We moreover calculate the values of IT portfolios based on the approach of Beer et al (2013), which is based on the common portfolio risk term of Markowitz, and compare the results of both methods.

We simulate three different IT project networks with three different connectivity degrees – low, medium, and high. We define 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 realistically not all projects in an IT portfolio will be likewise dependent on each other. In our simulation, the IT portfolios consist of 20 projects, which leads to 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 results in a connectivity degree 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. Like previously mentioned, we compare the results or our approach to the one based on Markowitz. Therefore, as w_{ij} can be considered equivalent to the pseudo correlation values ρ_{ij} of (1), we use the simulated values of w_{ij} correspondingly for ρ_{ij}.

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	

As previously explained, the parameter α determines the trade of between exogenous and endogenous factors within alpha centrality calculation. To investigate the coherence between α and the results of our approach, we simulated three different scenarios for a low, medium and high value of α. Since $0 < \alpha < \lambda_1^{-1}$, the minimum value is close to zero and the maximum value is close to the maximum eigenvector of λ_1^{-1}. Table 2 presents the results of our simulation for each chosen level of α and each connectivity degree.

Table 2. The IT Portfolios' Value Result of the Evaluation			
Results of Φ for	IT portfolio's Connectivity Degree		
	Low	Medium	High
$\alpha =$ low	1,143,550.11	1,143,595.97	1,143,534.95
$\alpha =$ medium	1,138,225.39	1,137,787.47	1,136,264.08
$\alpha =$ high	1,114,912.61	1,058,771.15	1,027,679.85
Markowitz-based	1,132,345.54	1,129,534.53	1,117,684.68

We performed the simulation several times and the results were reproducible. For a more convenient comparison of the results of our approach with the one based on Markowitz, we provide the results of the evaluation in the following figures. Figure 5 presents the results of our approach with three different values for alpha ($\Phi_1^*, \Phi_2^*, \Phi_3^*$). Figure 6 presents the 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 by either using the Markowitz-based method (cf. (1)) or our approach (cf. (3)).

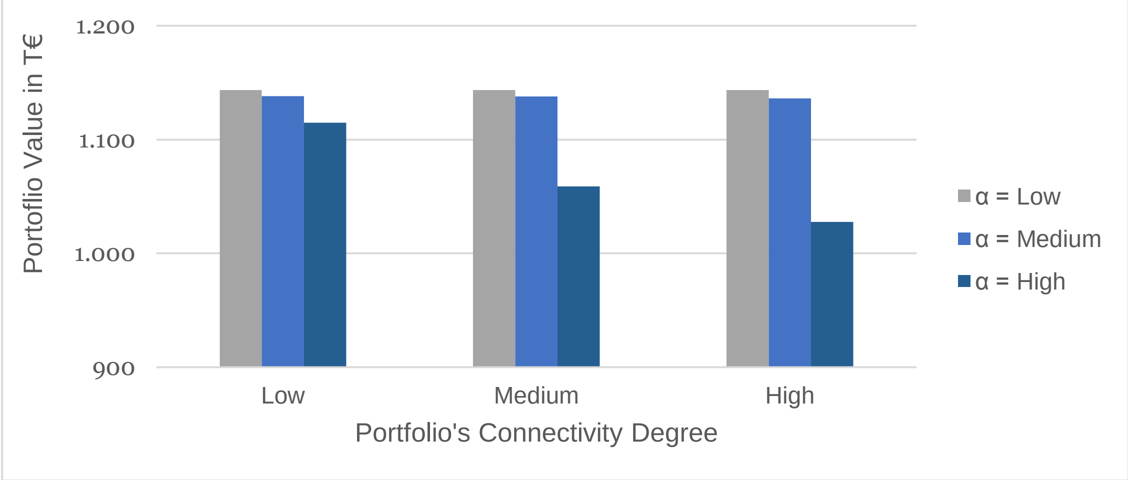

Figure 5. Evaluation of the Results

Based on the findings presented in Figure 5, we were able to show that increasing α, which implicates 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 risk and thus have a smaller risk adjusted portfolio value. Since for low and medium values of α, the result of our approach is fluctuating about 1% from the result of the Markowitz-based approach, 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 weightings 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 more important and consequently the simulation shows significant differences regarding the consideration of characteristic dependency structures between the two different IT portfolio evaluation approaches. Depending on the connectivity of the specific IT portfolio, the Markowitz based approach leads to an overestimation of the risk adjusted portfolio value between about 1.5% – 8% 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.

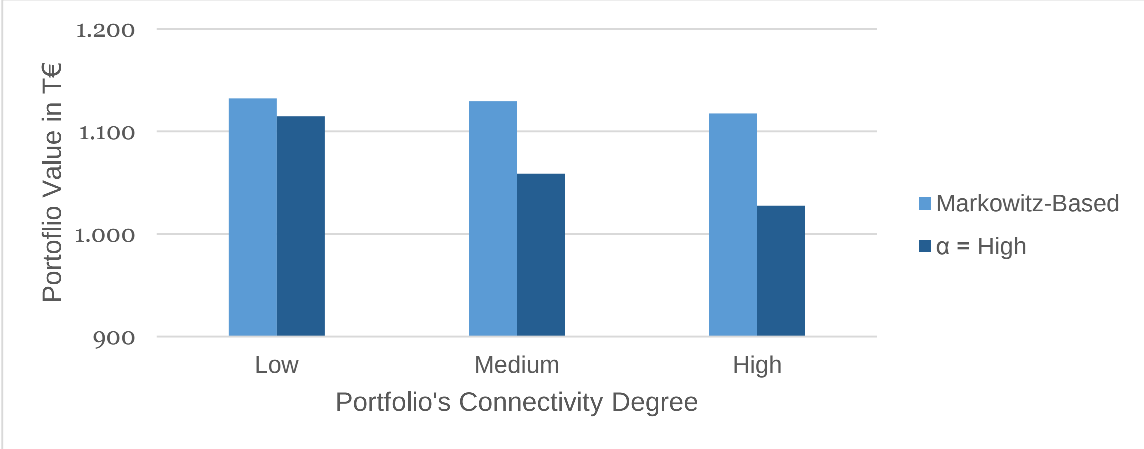

Figure 6. Evaluation of the Results

Based on our simulation results we in particular can constitute that for IT portfolios with a low degree of connectivity, the risk adjusted portfolio value using our approach and using the Markowitz-based method are relatively close to each other and only differ about 1.54%. This implies that, the risk of over- and underestimation in IT portfolios with a lower connectivity degree is comparably low. For IT portfolios with a medium (16%) degree of connectivity, the respective value accounts for about 6.26% and for portfolios with a high (26%) degree of connectivity even for 8.05%. Therefore we can constitute, that the probability for underestimating risk or overestimating the risk adjusted IT portfolio value increases with the number and strength of directly and indirectly dependent project in an IT portfolio.

Conclusion, Limitations, and Outlook

Our novel approach integrates various kinds of direct and indirect (transitive) dependency between IT projects and thus enables a holistic, quantitative, value-based IT portfolio evaluation in a feasible way. By considering IT portfolios as IT project networks and using alpha-centrality to investigate and evaluate underlying dependency structures, we faced the major challenge stated by Benaroch and Kauffmann (1999) and conveyed a model from another academic discipline to IS research. We furthermore adopted alpha-centrality and combined it with an integrated approach for IT project and portfolio evaluation provided by Beer et al. (2013), to derive an encompassing approach for value-based IT portfolio evaluation that appropriately considers the risk emerging from characteristic dependency structures as well as cost and benefits of IT portfolios. By the means of simulation, we examined the validity of our approach per se, and investigated the benefits of our approach in comparison to the approach of Beer et al. (2013), which however is based on the well-established approach of Markowitz (1952). The results of our simulation imply that for low connectivity of the IT project network, which refers to a low number of dependencies in the corresponding IT portfolio, the results of our approach are comparable with the result of the Markowitz-based approach. This indicates the validity of the results of our approach. For IT portfolios with a high number of dependencies, our approach however yields different results compared to the one that is based on Markowitz. This however seems quite plausible, since the Markowitz-based approach lacks the consideration of (systemic) risks associated to transitive dependencies, and consequently overestimates the overall IT portfolio value.

Nevertheless, our approach has also some limitations that are outlined in the following. Since this is a mathematical deductive approach, we had to make a few simplifying assumptions and restraints, which do no picture reality adequately. For instance, we defined an IT project as accounted to one specific period in time. In reality, there may be IT projects, which, even if subdivided into smaller subprojects, have to be accounted to more than one period of time. Our assumption of normally distributed cash flows might also not always picture reality, but 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 will 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 picture reality for each kind of asset, it seems plausible for at least the most important intra-temporal dependencies and we considered it as appropriate for a first step towards an integrated value-based IT portfolio valuation. Finally, the validity and contribution of our approach has only been indicated by the means of simulation. For further evaluation and improvements, a recurrent application of our approach to real world scenarios is topic to further research. Moreover, future research should feel encouraged to investigate whether the integration of different risk measures can yield even more plausible results regarding the consideration of risk associated to direct and indirect dependencies or whether the existing limitations can be reduced. Furthermore, an extension from the integrated ex-ante evaluation of IT portfolios to an integrated ex-nunc IT portfolio controlling and management may be a relevant and interesting extensions for a holistic IT portfolio management.

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