Kock, A., Schulz, B., Kopmann, J., & Gemünden, H. G. (2020). Project portfolio management information systems' positive influence on performance – the importance of process maturity. *International Journal of Project Management*, *38*(4), 229–241. https://doi.org/10.1016/j.ijproman.2020.05.001

Project Portfolio Management Information Systems' Positive Influence on Performance – The Importance of Process Maturity

ABSTRACT

Companies increasingly support their project portfolio management processes with specific software and the market for IT solutions is growing. While project portfolio management information systems (PPMIS) promise to improve the quality of the management process and eventually portfolio performance, it is unclear whether they actually deliver on this promise. We lack empirical evidence for the actual benefits of PPMIS and knowledge on the conditions under which PPMIS application is most beneficial. Using a sample of 181 project portfolios, this study shows for the first time that PPMIS application is overall positively associated with the quality of portfolio management processes and project portfolio success. However, moderation analyses further reveal that these effects only materialize when formalization of single project management, project portfolio management, and risk management are sufficiently high. Surprisingly, the benefits of PPMIS application do not depend on portfolio complexity (size, project interdependency, dynamics).

Keywords: Project portfolio management information systems, project portfolio success, management quality, process formalization, complexity

Project Portfolio Management Information Systems' Positive Influence on Performance – The Importance of Process Maturity

1 INTRODUCTION

The projectification of the firm is an ongoing trend that has persisted over the last decades and requires organizations to manage portfolios of multiple projects (Bredin and Søderlund, 2006; Midler, 1995; Schoper et al., 2018). With the increasing importance of project portfolio management (PPM), a plethora of software vendors have started to offer a variety of project portfolio management information systems (PPMIS) solutions and the market is growing quickly (Ahlemann, 2009; Ahlemann et al., 2013; Meyer, 2005; Stang and Handler, 2013). However, Meyer (2005) showed that less than 20% of the organizations surveyed had special software for project portfolio management, but around 83% used special software for schedule and time management in single project management. Even more recent studies show that firms still focus on single project management IT solutions (Besner and Hobbs, 2012).

PPMIS promise to increase transparency over the project landscape and to improve decision-making regarding strategic alignment, prioritization, resource allocation, and risk management. However, these promises are questionable, because PPM is still an immature management discipline (Martinsuo, 2013) and may lack the necessary maturity to effectively exploit the advantages of IT support. Furthermore, PPM is a complex managerial task that requires sophisticated approaches, while existing PPMIS are still quite young and may suffer from "teething troubles" (Gemünden et al., 2018). In general, the current literature still shows failures of information systems implementation, where business IT projects did not realize their benefits (Baghizadeh et al., 2019; Einhorn et al., 2019).

So far, no empirical proof for the benefits of PPMIS exists. Besner and Hobbs (2008, 2012) analyzed the usage of a broad range of project management tools and identified a cluster of project portfolio related management practices (e.g., project priority ranking, project portfolio analysis up to graphical presentations of the portfolio). Li et al. (2015) considered a case study in which an advanced information system was used to tackle the complex multi-project management. While these studies give some indication that PPMIS are relevant in practice, they do not assess the performance impact of PPMIS.

However, a range of studies have analyzed *single* project management IT solutions and report positive performance effects. For example, Ali et al. (2008) and Raymond and Bergeron (2008) showed an indirect relationship with project success. In the field of innovation management, Barczak et al. (2007) showed that a more frequent usage of IT tools during the development phase of projects is associated with higher market performance. Similarly, Kroh et al. (2018) reported a positive relationship between intensive use of IT and innovation performance. And Mauerhoefer et al. (2017) showed that more frequent usage of IT tools positively affects new product development by increasing the IT leverage competency. Caniëls and Bakens (2012) demonstrated that project management information systems positively relate to project managers' decision-making quality.

To the best of our knowledge, however, no empirical study has analyzed the performance consequences of information systems for project portfolio management. The current study addresses this gap with the following research question: *How and by which mechanisms do PPMIS affect project portfolio success?* We hypothesize that the application of PPMIS indirectly increases project portfolio success by improving the management quality of the project portfolio process (Jonas et al., 2013; Teller et al., 2012).

Furthermore, our theoretical framework suggests two critical fits: First, in order to benefit from a PPMIS, we suggest that firms should have reached a *sufficient level of maturity* in their single project management process, their project portfolio process, and their project and portfolio risk management process. We therefore expect that the positive performance impact of a PPMIS increases with the maturity of these processes. Such a fit between information systems and organizational processes, resources, and capabilities has been documented as a critical requirement in the literatures on Information systems (Bergeron et al., 2001) and operations research (Tenhiälä, 2011).

Second, we expect that there should be a fit between PPMIS application and *task complexity* in terms of a portfolio's size, interdependence, and dynamics. This reasoning is based on organizational contingency theory (Donaldson, 2001), which suggests that the usefulness of organizational instruments (e.g., centralization) depends on the internal or external situation (e.g., environmental turbulence). Hanisch and Wald (2012) showed that the contingency approach is widely used in project management, and empirical research confirmed that the success of managerial practices in PPM depends on the context (for a review see Martinsuo, 2013), for example portfolio complexity (Teller et al., 2012) or environmental turbulence (Voss and Kock, 2013). It is therefore possible that with increasing portfolio complexity, PPMIS application is more beneficial.

We empirically address these hypotheses using a sample of 362 informants from 181 project portfolios. This study contributes to the literature on project and project portfolio management in several ways: (1) we present first quantitative results showing the relationship between PPMIS application and project portfolio success; (2) we observe the mechanisms by which PPMIS application affects project portfolio success; (3) we analyze the complementary effect for PPMIS application of different types of PPM formalization; and (4) we suggest contingencies of the performance effects under different forms of portfolio complexity.

The rest of the paper proceeds as follows: First, we describe how IT can support the phases of the project portfolio process. In the second step, we develop hypotheses on the influence of PPMIS application on the quality and success of project portfolio management. Then we develop contingency hypotheses on the complementary effects of formalization and the moderating impact of portfolio complexity. After describing the methods and data, we empirically test our hypotheses. Finally, we conclude by discussing our findings.

2 PROJECT PORTFOLIO MANAGEMENT INFORMATION SYSTEMS

2.1 Phases of Project Portfolio Management

A project portfolio refers to a group of projects that compete for common resources. These projects can be either internal projects that support an organization's core business or external projects that deliver products and service to external customers. The dedicated management of a portfolio accompanies project initiatives from their initial idea until their realization and focuses on the overall portfolio objectives. Project portfolio management decides whether a project is selected for execution, prioritizes between projects and allocates resources accordingly, steers the project portfolio and identifies and exploits synergies between projects, manages portfolio-wide risks in their entirety, and fosters cross-project learning and competence development (Blichfeldt and Eskerod, 2008; Padovani and Carvalho, 2016; Teller and Kock, 2013). The main areas of application can be clustered in four phases: portfolio structuring, resource allocation, portfolio steering, and portfolio learning (Beringer et al., 2013; Jonas, 2010). Each phase comes along with several challenges for the project portfolio management that are highlighted subsequently.

Portfolio structuring. Portfolio management's main task is to decide whether a project idea is selected for funding or not (Cooper et al., 2001). For this purpose, organizations have established various methods and tools to evaluate and prioritize project proposals. These approaches try to reflect manifold potentially conflicting goals such as strategic fit, maximal economic benefits, exploitation of complementary projects, and an optimal balance (e.g., with regards to exploration and exploitation, risk and profitability, or short- and long-term returns) (Cooper et al., 2001). Furthermore, multiple stakeholders are involved in project selection, who all may have their own agendas (Beringer et al., 2013; Winch, 2007). Thus, the main issue of portfolio structuring is to establish a common approach that is accepted and transparent to all relevant stakeholders to evaluate and prioritize projects in a consistent manner.

Resource allocation. The allocation of resources across multiple projects represents a major challenge for organizations (Engwall and Jerbrant, 2003). Especially the availability of bottleneck resources—resources with limited capacities that determine the project executions in the project portfolio (Melchiors et al., 2018)—is crucial for project and portfolio success. Furthermore, small projects not considered by the portfolio management additionally hog resource capacities (Blichfeldt and Eskerod, 2008). Thus, resource management aims to gain transparency about the actual resource demand, as well as the resources' availability and competences. In addition, the assignment of resources ideally reflects the project priorities.

Portfolio steering. The portfolio of ongoing projects needs to be coherently coordinated and steered. Project changes need to be considered in a way that aims at the goals of the organization and not only the single project (Nguyen et al., 2018). Individual and cross-project risks can be handled more efficiently on the portfolio level (Teller et al., 2014). In order to exploit the advantages and synergies of an orchestrated and coherent project portfolio, managers need to simultaneously process information from various different projects and assess projects and upcoming issues in a consistent manner.

Portfolio learning. Projects are temporary organizational endeavors and are dissolved after completion. Thus, the created knowledge and competences need to be secured, disseminated and re-used in the organization (Brady and Davies, 2004). Facilitating cross-project learning and exploiting the gained knowledge and competences requires a carefully managed process (Ekrot et al., 2016; Prencipe and Tell, 2001). However, project team members are often not motivated to document and share their own knowledge and many organizations fail to effectively use documented lessons learned (Bartsch et al., 2013).

In sum, project portfolio management strives to master the complexity caused by multiple and potentially ambiguous goals, by interdependencies between projects or between projects and routine organization, by the lack of transparency on resource assignment and availability, and the fragility of knowledge and competences that are created in projects. As a consequence, portfolio managers may benefit from using information systems as support.

2.2 Information Systems for Project Portfolio Management

Information systems are in general considered to improve information processing and the assessment of complex situations, and various measures have been developed to capture these effects (DeLone and McLean, 1992, 2003). DeLone and McLean (1992, 2003) showed in their success model that an information system's success is realized through its usage. This positive influence can also be assumed for PPMIS. The PPMIS used in practice vary from highly complex all-round solutions over specialized solutions for individual PPM activities (e.g. for competence management) to simple office applications that firms use to support their PPM phases (Meyer, 2019). Table 1 presents the PPM phases and the main application areas for information systems, summarizes main challenges for each PPM phase, and shows merits for using a dedicated information system. Hence, each of the described portfolio management phases can directly benefit from the use of dedicated information systems:

- Dedicated information systems can support *portfolio structuring tasks* by mastering the complexity of various potentially conflicting goals in mathematical models and by providing transparency and traceability for all participating parties (Costantino et al., 2015; Geng et al., 2018; Killen and Kjaer, 2012). Even by using self-learning algorithms the data source has to be huge to calculate predictable solutions and the used information has to be handled carefully to avoid wrong correlations (Costantino et al., 2015).

- Dedicated information systems can support *resource allocation tasks* by providing a database for documenting resource demand and capacity, for analyzing and monitoring their availability in order to identify bottlenecks early on, and to track and communicate resource skills and competences (Abrantes and Figueiredo, 2015; Melchiors et al., 2018). Although it is still not possible to capture all knowledge and complexities of the resource allocation process (Melchiors et al., 2018), PPMIS can still support decision-making.
- Dedicated information systems can support *portfolio steering tasks* by capturing and consolidating the information of the portfolio's single projects and by compiling portfolio overviews and analyses (Ayub et al., 2019). Regarding portfolio risk management, information systems can support the process of identifying and tracing project and portfolio-wide risks and dependencies and enable comprehensive portfolio risk analyses (Ahmadi-Javid et al., 2019; Bos-de Vos et al., 2019; Neumeier et al., 2018).
- Dedicated information systems can support *portfolio learning tasks* by providing a database for documenting, sharing, and finding knowledge and by making competences transparent to other projects and the organization (Duffield and Whitty, 2016). The system can only support knowledge transfer if the company's culture promotes learning—even from mistakes (Duffield and Whitty, 2016).

Meyer and Ahlemann (2014) examined software solutions for PPM and their functionality in more detail. Based on these considerations we define project portfolio management information systems (PPMIS) as dedicated IT systems that support the described tasks which have to be managed during the main project portfolio management phases. We understand *PPMIS application* as the extent, to which the main project portfolio management tasks are supported by dedicated information systems.

Table 1. Project Portfolio Management Information Systems

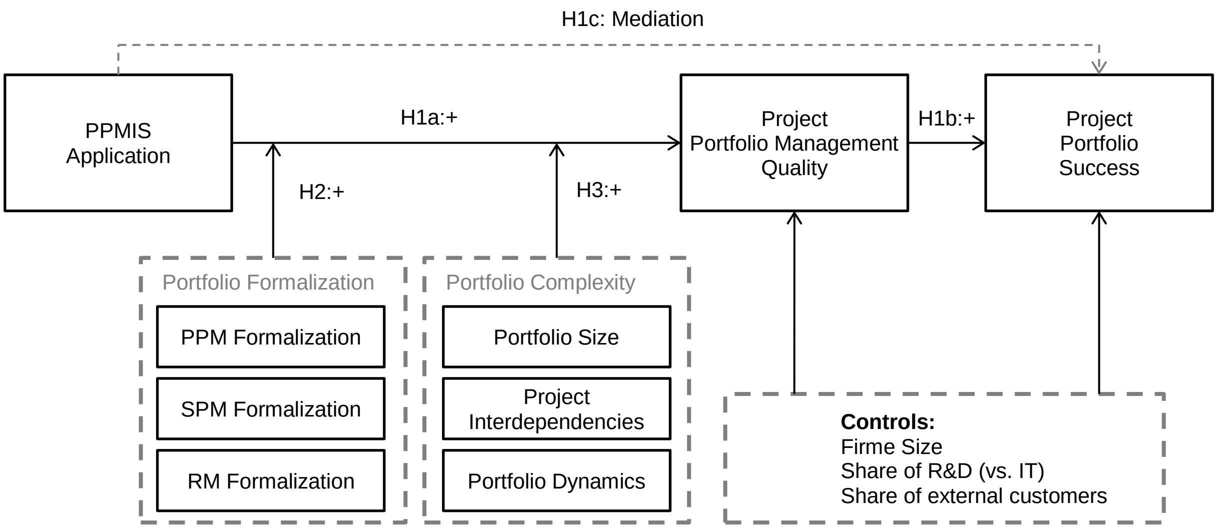
PPM phase	Main application areas for information systems (Information systems for…)	Main challenges	Merits of PPMIS (examples)
Portfolio Structuring	- Prioritization (… project selection and prioritization.)	- Establish a consistent approach for project evaluation and prioritization (Geng et al., 2018) - Prioritize project proposals and select projects for execution (Costantino et al., 2015) - Identify synergetic portfolio effects (Killen and Kjaer, 2012)	- Mathematical models for project evaluation and selecting - Visualization of portfolios - Scenario analyses - Transparency and traceability of portfolio decisions
Resource Allocation	- Resource Allocation (… resource allocation and detection of bottlenecks.) - Competence Management (…recording of employees' competences.) *	- Allocate according to priorities and employees' competences (Abrantes and Figueiredo, 2015) - Identify resource bottlenecks (Melchiors et al., 2018)	- Information gathering - Analysis of resource bottlenecks - Skill transparency
Portfolio Steering and Risk Management	- Portfolio steering (… monitoring project portfolio performance.) - Risk management (… risk identification and assessment in our project portfolio.)	- Monitor performance, identify bad performing projects (termination) (Ayub et al., 2019) - Identify and exploit synergies (Killen and Kjaer, 2012) - Identify and mitigate/avoid portfolio risks (synergies in risk handling / cluster risks) (Ahmadi-Javid et al., 2019; Neumeier et al., 2018)	- Consolidated reporting - Comparability between projects - Models for portfolio risk analyses - Scenario analyses
Portfolio Learning	- Competence Management (… recording of employees' competences.) * - Project learning (… the documentation and communication of lessons learned.)	- Document and communicate lessons learned (Duffield and Whitty, 2016) - Identify and create transparency about gained competences (Geng et al., 2018)	- Information gathering - Accessibility of information - Competence transparency - Knowledge dissemination

* Item "recording of employees' competences" applies to two PPM phases: Resource Allocation and Portfolio Learning

3 CONCEPTUAL FRAMEWORK AND HYPOTHESES

Figure 1 shows the conceptual framework of this study. Overall, we argue that the application of PPMIS supports project portfolio management and thus contributes to the success of a project portfolio. This is done by improving the efficiency and the quality of managerial decisions, which we operationalized by using project portfolio management quality (Jonas et al., 2013) as a mediator. Furthermore, PPMIS require defined project and project portfolio processes to take full effect, which is why we assume positive moderating effect of portfolio formalization. Finally, we consider the circumstances in which PPMIS may be most beneficial by including moderating effects of portfolio complexity. In the following, we will develop the arguments for each of the hypotheses in more detail.

Figure 1: Conceptual Framework



PPM Project Portfolio Management, PPMIS Project Portfolio Management Information Systems, SPM Single Project Management, RM Risk Management, R&D Research and Development

3.1 Performance Impact of IT Support

Project portfolio management quality is defined as "the degree of excellence to which the project portfolio management process is executed" (Jonas et al., 2013: 216). Following Dammer et al. (2006), Jonas et al. (2013) conceptualized this process quality along the three dimensions collaboration quality, information quality, and allocation quality. *Collaboration quality* is defined as "the degree of excellence and mutual support throughout the project portfolio management process" (Jonas et al., 2013: 218). *Information quality* is "the transparency that is achieved over the whole scope of projects of a certain portfolio and the availability and reliability of project status information supplied by project and line managers" (Jonas et al., 2013: 217). *Allocation quality* means "effective, efficient, and reliable assignment and redistribution of human resources within the project portfolio" (Jonas et al., 2013: 217). Unger et al. (2012: 678) argued for another quality dimension called *termination quality*, which describes "how well the decision-making and termination process is executed, characterizing the effectiveness of the abortion process of single projects". Termination quality therefore assesses in how far project portfolio management is able to terminate projects if they do not add value anymore. All four dimensions are closely related but distinct and collectively define the quality of the project portfolio management process, regardless of the specific management activities (Jonas et al., 2013).

PPMIS support the portfolio management through capturing and processing relevant information. It has been shown that the application of single project management information systems did not create an overflow of information that could paralyze management decisions. Rather, they enable managers to make better decisions on a more comprehensive and relevant information basis (Caniëls and Bakens, 2012; Liu et al., 2019). We think this also applies to PPMIS through capturing and processing relevant information for the prioritization of projects, the allocation of resources, the identification of bottlenecks, and the evaluation of ongoing projects. Furthermore, the application of PPMIS can foster the rigor and transparency of the project portfolio management process itself (Artto and Dietrich, 2007), which in turn positively affects the collaboration quality (Teller et al., 2012). Thus, we expect that the application of PPMIS positively influences PPM quality. We expect that the more the project portfolio management tasks are supported by dedicated information systems the better will be the quality of the project portfolio management in terms of collaboration, information, allocation, and termination quality.

H1a: PPMIS application is positively related to PPM quality.

Project portfolio success has been extensively discussed in the literature and the construct is considered to be multi-dimensional (Cooper et al., 2001; Jonas, 2010; Kester et al., 2014; Kopmann et al., 2017; Meskendahl, 2010; Müller et al., 2008; Petro and Gardiner, 2015). Cooper and colleagues (1999, 2001) defined a portfolio as successful, if it achieves the maximal value in terms of company objectives, if its composition reflects the firm's strategic business priorities, and if it is harmoniously balanced with regards to certain characteristics such as exploratory vs. exploitative projects, or project benefits and project risk. In this study, we followed recent empirical research that distinguishes between five dimensions of project portfolio success (Jonas et al., 2013; Kock et al., 2015; Teller and Kock, 2013; Teller et al., 2012; Voss and Kock, 2013): Portfolio success covers on the one hand the effectiveness of the project portfolio in terms of choosing the right projects, by taking into account the fit between portfolio and strategy, the extent the portfolio helps preparing for the future, and the balance within the portfolio (risks, innovativeness, long- and short-term opportunities) (Meskendahl, 2010; Teller et al., 2012). On the other hand, it covers the efficiency of the project portfolio in terms of doing the projects right, by looking at the success of all the containing projects and how synergies between the projects are used (Jonas et al., 2013; Voss and Kock, 2013).

Project portfolio management quality is likely to be a central antecedent to project portfolio success (Jonas et al., 2013; Teller et al., 2012). In general, better PPM quality—i.e., higher quality of information, better collaboration between stakeholders, faster allocation of resources to projects, and the ability to enforce a necessary project termination—will improve portfolio decision-making and thus project portfolio success (Jonas et al., 2013; Teller et al., 2012; Unger et al., 2012). Jonas et al. (2013) provide empirical evidence for this relationship in a longitudinal study of project portfolios, and Teller et al. (2012) present similar evidence in a cross-sectional study. Unger et al. (2012) show that termination quality is strongly related to strategic fit. In accordance with previous research, we therefore assume:

H1b: PPM quality is positively related to project portfolio success.

PPM quality captures the excellence of management activities along the whole project portfolio management process. PPM quality is therefore likely to mediate the relationship of any process-improving management practices (such as PPMIS application) on project portfolio success. Dammer et al. (2006) and Jonas et al. (2013) conceptualized PPM quality exactly for this reason – to serve as an immediate measure for the effects of management practices aimed to improve more distal outcomes such as project portfolio success. Information technology aimed at improving and supporting portfolio management activities will therefore only indirectly affect portfolio success by improving management quality. Hence, we postulate for a mediation effect:

H1c: PPM quality mediates the relationship between PPMIS application and project portfolio success.

3.2 The Moderating Role of Formalization

The aim of IT is to support business processes and methods. However, IT and business processes affect each other. On the one hand, business processes are often aligned to fit the requirements of a certain IT solution. On the other hand, IT solutions require explicit processes to unfold their full potential.

Following the conceptualization of Teller et al. (2012) we define formalization as the extent to which processes are clearly specified and defined procedures and methodologies are followed. We expect that more formalized processes are more likely deliver information that is sufficiently accurate, current, reliable and valid across projects, so that all project managers, line managers, and decision-makers, who use this information, have the same understanding. Formalized processes ensure that information is consistent and well-understood (Kock and Gemünden, 2016). If the information quality is not secured by sufficiently mature processes, models can become garbage-in-garbage-out-models. Several studies document that formalized processes increase an organization's data quality and IT capabilities (Jeffery and Leliveld, 2004; Thornley et al., 2019).

Beside the direct performance effect of formalization (Schultz et al., 2019a; Teller and Kock, 2013; Teller et al., 2012), we therefore expect that formalization of the following three main processes behaves complementary to the application of PPMIS: the single project management process, the project portfolio management process, and the project and portfolio risk management process.

- *Single project management formalization* is the extent to which the single project management processes are standardized and uniformly managed (Jonas et al., 2013; Teller et al., 2012). A high formalization assures that single project information is complete, comparable, and current. This is a prerequisite for the effective processing of information on the PPM level.
- *Project portfolio management formalization* is the degree to which the PPM process is clearly specified and follows a defined structure of phases and decision points (Teller et al., 2012). This enables all stakeholders to have a common and uniform understanding of the procedures, quality gates and requirements of portfolio decisions (Ekrot et al., 2018). As a consequence, PPMIS should provide decision support in terms of information

quality but also improve decision transparency, process predictability, and mutual collaboration.

- *Risk management formalization* is the degree to which formal portfolio risk management rules and procedures are practiced (Teller and Kock, 2013). Such practices not only benefit from PPMIS (e.g., portfolio risk analyses, scenario analyses) but also enrich the information processed by PPMIS.

Overall, we assume that the formalization in each of these three processes will complement the application of PPMIS in its effect on PPM quality (i.e., formalization fosters the beneficial use of PPMIS and vice versa):

H2: The relationship between PPMIS application and PPM quality is more positive when a) PPM formalization, b) single project management formalization, or c) risk management formalization is high (positive moderation).

3.3 The Moderating Role of Portfolio Complexity

Project portfolios strongly differ in size (number of parallel projects), project types, and project interdependencies. To take this into account, we follow the contingency theory (Donaldson, 2001) with portfolio complexity as the main task contingency. Project management research has often applied contingency theory (Hanisch and Wald, 2012; Søderlund, 2011), and task complexity is a major characteristic that influences which organizational design should be applied to organize projects (Dietrich et al., 2013; Hoegl et al., 2004; Shenhar, 2001) or project portfolios (Teller et al., 2012; Voss and Kock, 2013).

With a project portfolio's increasing task complexity in terms of size, interdependence, and dynamics (i.e., frequency of changes and modifications to the portfolio), PPMIS' positive impact on PPM quality should increase. Due to increasing complexity the project portfolio loses transparency, which may be counteracted by using PPMIS. According to the revised model of

DeLone and McLean (2003), an information system's *information quality*, *system quality* and *service quality* will positively impact intention and actual use of the system. This will in turn positively influence net benefits at the individual group and organizational level. Our hypothesis builds mainly on the *system quality* and accordingly we have used such measures in our operationalization of PPMIS application. We assume that the value of these dedicated PPMIS functions will increase with user experience and complexity of the tasks they have to manage.

With increasing complexity, it may become more difficult to obtain current and reliable data. In addition, information about interdependencies between projects may also be more difficult to get than information about single projects. Thus, two counter-acting influences may exist: on the one hand, with increasing task complexity the benefits of PPMIS should rise, but on the other hand, the efforts to get timely information may also increase, and the information's validity, reliability, and accuracy may decline with increasing task complexity. It is difficult to assess which influence will be stronger.

Since our study is to our best knowledge the first to analyze the effects of PPMIS we can only build on studies that have analyzed information systems' support of single project management. For example, Ali et al. (2008) find that greater information quality and higher project complexity are the dominant factors explaining higher levels of system utilization and that higher usage of project management software is positively related to perceived project managers' performance. In addition, greater system functionality and ease of use positively relate to increased software usage and performance (Ali et al., 2008). We therefore assume that the positive moderation effects prevail:

> *H3: The relationship between PPMIS application and PPM quality is more positive when a) portfolio size, b) project interdependency, or c) portfolio dynamic is high.*

4 METHOD

4.1 Sample and Data

We conducted our study with firms from a range of German industries. The object of analysis was the project portfolio of the firm (or a business unit within a large firm). We considered project portfolios with at least 20 projects to make sure that the firms face portfolio management challenges. In each portfolio we addressed two informants from different management levels. The first informant (a “decision maker” such as CEO, CIO, head of R&D) had decision authority over the portfolio regarding project initiation or termination. These informants provided information about the success of the project portfolio. The second informant (“coordinator” such as head of PMO, portfolio manager, department manager) had a good overview of the portfolio and management processes. The coordinators provided insights into the structures, procedures, and processes of PPM and its quality. This approach provided different hierarchical perspectives on procedures and outcomes and addressed common method bias by using different informants for dependent and independent variables.

We contacted 850 firms by e-mail to inform them about the study and solicit their participation. As an incentive we promised all participants a detailed individualized report and the opportunity to attend a conference on the findings at the end of the research. After the mailing we made follow-up phone calls. The 332 registered informant-duos received an e-mail explaining the questionnaires with an introduction describing the terms and definitions. Again, follow-up phone calls ensured an increased response rate. Overall, we received 384 completed questionnaires (189 from decision makers and 195 from coordinators), which resulted in 184 matched dyads with data from both types of informants for their project portfolio. Some questionnaires had missing data, so the final sample consisted of 181 project portfolios.

Table 2 displays sample characteristics and informs about the type of portfolios. The firms come from diverse industries and show a reasonable spread in firm size (employees and revenue). As can be seen, the sample still contains considerable variance regarding portfolio focus and size (number of parallel projects and portfolio budget). Overall, the sample covers a wide range of companies and projects.

Table 2. Sample Characteristics

Industry		**Focus of portfolios**	
Automotive	26%	IT & (re-)organization	36%
Electronics/IT	18%	Research & development	32%
Finance	16%	Investment & construction	12%
Construction and utility	11%	No focus / mixed	20%
Health care	8%		
Logistics	7%		
Pharmaceuticals/chemicals	5%		
Others	9%		
Employees		**Revenue**	
<500	32%	<100 Mio €	15%
500-2000	29%	100-500 Mio €	27%
>2000	39%	501-2,000 Mio €	20%
		>2,000 Mio €	38%
Portfolio budget		**Number of parallel projects**	
<10 Mio €	25%	<25	23%
10-30 Mio €	29%	25-50	24%
30-100 Mio €	22%	51-100	28%
<100 Mio €	24%	>100	25%

4.2 Measurement

Except for the measure of PPMIS application we used existing scales from the literature. All scales were pretested with 12 representatives from academia and industry to assure constructs' face validity, improve item wording, and remove ambiguity. All measures used seven-point Likert scales (1 = "strongly disagree" to 7 "strongly agree") unless stated otherwise. The Appendix shows each construct's exact item wordings.

Dependent Variable. Project portfolio success was measured as a second-order construct along five dimensions taken from Teller and Kock (2013), Voss and Kock (2013) and

Kock et al. (2015): *Strategy implementation* captured the degree to which the company strategy is successfully implemented by the project portfolio (4 items); *future preparedness* assessed to which degree the current portfolio creates competences for the future (3 items); *portfolio balance* reflects whether the portfolio is well balanced according to risk and innovativeness (3 items); *average project outcome* assessed the average commercial success across all projects in the portfolio (4 items); *synergy exploitation* finally captured the degree to which the portfolio is more valuable than the sum of its projects by measuring whether synergies across projects are leveraged and redundancies avoided (3 items). The decision maker assessed project portfolio success, so that different informants assessed independent and dependent variable in order to reduce common method variance. However, for validation purposes, we also asked coordinators to evaluate project portfolio success. The two assessments highly correlated ($r = 0.57$, $p < 0.00$), which gave us confidence in their validity.

Mediator Variable. We used the multi-dimensional construct by Jonas et al. (2013) and Teller et al. (2012) to measure project portfolio management quality. They described the construct as a process variable along the dimensions: information quality, collaboration quality, and allocation quality. Information quality (4 items) described the extent of transparency over the portfolio by uniform quick and easy accessible information over the whole project landscape. Collaboration quality (3 items) captured in how far project managers supported each other directly in case of problems and in how they collaborate across projects. Allocation quality (4 items) measured how smoothly resource allocation proceeded, the process is based on prioritization, and promises are binding. Following research on project termination in a portfolio context (Unger et al., 2012), we added a fourth dimension called termination quality (4 items), which captured the extent to which projects are actually cancelled early if necessary. The coordinator informant assessed PPM quality.

Independent variable. Prior literature did not provide existing scales for PPMIS application. We therefore developed a scale that tapped the usage of information systems based on an analysis of the main tasks along the project portfolio management process. We used six items for the activities prioritization, resource allocation, competence management, risk management, portfolio steering, and project learning that asked whether these activities were supported by dedicated information systems. Because a wide variety of different software solutions exist, we purposefully did not ask about specific tools but rather the specific activities they support. Taken together these six items capture the degree of PPMIS application for the main PPM activities.

Moderator variables. Project portfolio management formalization (4 items) assessed the degree to which the PPM process is clearly specified and follows a defined structure of phases and decision points (Teller et al., 2012). Single project management formalization (5 items) measured the extent to which the project management processes were standardized and uniformly managed in the company. The construct was taken from previous research (Jonas et al., 2013; Teller et al., 2012). Risk management formalization (5 items taken from Teller and Kock, 2013) assessed "the degree to which formal rules and procedures, such as the existence of standardized forms and workflows, exist for the portfolio risk management process" (Teller and Kock, 2013: 823). Portfolio complexity was assessed by the three variables portfolio size, project interdependency, and portfolio dynamics. Portfolio size was assessed using the logarithm of the annual portfolio budget in million Euros. Project interdependency is defined as the "the extent to which the projects in the portfolio depend on and are influenced by each other" (Teller et al., 2012: 601). The variable was measured with four items taken from Teller et al. (2012) and includes interdependencies between projects regarding resources (pooled interdependence), re-use of knowledge (sequential interdependence), reciprocal exchange between concurrent projects, and shared customers/suppliers (market interdependencies).

Finally, portfolio dynamics used two items to assess the frequency of changes and modifications in the portfolio over the course of a year (Teller et al., 2014).

Control variables. We controlled for three additional variables that potentially affect PPM quality and project portfolio success. First, firm size might be positively related to the maturity of project and project portfolio management capabilities, but establishing high quality communication and transparency over the portfolio might be easier in smaller firms. We measured firm size by the natural logarithm of the number of employees in the firm or business unit. Second, apart from portfolio complexity, the type of projects in the portfolio might have an effect on the mediator and dependent variable. R&D projects face more uncertainty and complexity than other types of projects. We therefore controlled for the R&D focus of the portfolio by including the percentage of R&D projects in the portfolio (ranging from 0 to 1=100%) as a control variable (Voss and Kock, 2013). Third, another project characteristic is whether the project customers are company-external or -internal. We included external customer focus as the percentage of projects in the portfolio that are directed to company-external customers as the final control variable (Voss and Kock, 2013).

4.3 Measurement Assessment

In order to assure reliability and validity of our measures, we first performed a principal components factor analysis (PCFA) of the items and calculated Cronbach's Alpha values. PCFA tested for unidimensionality of each scale by checking whether all related items loaded onto a single factor. The results showed that all items loaded onto their respective factors and there were no cross-loadings higher than .3. Cronbach's alpha values for all variables were above .7 (see appendix). We next performed a confirmatory factor analysis (CFA) with all latent variables. CFA-results are depicted in the appendix. According to the criteria defined by Hu and Bentler (1998) the measurement is acceptable. In particular, the CFA validated the second-order structure of project portfolio success and PPM quality by demonstrating an acceptable model fit and high and significant second-order factor loadings. Overall, the measurement can be considered satisfactory.

Although we used two types of informants, the reported results could still be subject to common method bias. We therefore conducted Harman's single-factor test using a PCFA and CFA with all items. The PCFA showed that the first factor explained only 22% of variance. The CFA model had an extremely poor fit (χ^2[740] = 2,770.1; CFI = .36; TLI = .32; RMSEA = .118; SRMR = .118). Both results suggested that common method bias was not a serious threat to the validity of our results.

5 RESULTS

5.1 Descriptive Findings

Descriptive statistics for the items of PPMIS application are depicted in table 3. As can be seen, some activities were more often supported by PPMIS than others. For example, firms use information systems more intensively for prioritization, resource allocation and portfolio monitoring than for competence management, risk management, and capturing of lessons learned. However, all items were significantly correlated with each other, which means that firms more likely apply information systems in several PPM activities than only in selected ones. This correlation also justified an aggregation to the single construct PPMIS (Cronbach's Alpha = 0.73).

Another interesting finding is that the mean values of all items were rather low and their variance was high. This suggests that while on average PPMIS application is relatively low, there are some firms with no IT support but others with rather strong support. Finally, all PPMIS activities are significantly correlated to PPM quality and project portfolio success, and the strength of the correlations is comparable across all six items. This shows their relevance and again justifies an aggregation. Table 4 shows the correlations and descriptive statistics for all constructs.

Table 3. Correlations and Descriptive Statistics of Items for PPMIS application

	Dedicated IS for...	M	SD	Min	Max	PPM quality	Portfolio success	1	2	3	4	5
1	Prioritization	3.10	2.26	1	7	.18	.19					
2	Resource allocation	3.40	2.12	1	7	.27	.17	.48				
3	Competence management	2.31	1.68	1	7	.21	.14	.21	.24			
4	Risk management	2.70	1.80	1	7	.30	.22	.26	.27	.33		
5	Portfolio steering	3.39	2.22	1	7	.25	.27	.45	.31	.21	.36	
6	Lessons learned	2.42	1.67	1	7	.24	.14	.27	.13	.32	.42	.42

n = 181, M Mean, SD Standard Deviation, PPM Project Portfolio Management, all correlations larger than .15 are significant (p < .05).

Table 4. Correlations and descriptive statistics

	Variables	M	SD	Min	Max	1	2	3	4	5	6	7	8	9	10	11
1	Project portfolio success	4.56	0.80	2.2	6.6											
2	PPM quality	4.43	0.76	2.3	6.2	.50										
3	PPMIS application	2.90	1.31	1.0	6.8	.29	.37									
4	PPM formalization	4.69	1.74	1.0	7.0	.30	.46	.28								
5	SPM formalization	5.30	1.09	1.8	7.0	.36	.52	.28	.36							
6	RM formalization	3.82	1.47	1.0	7.0	.18	.39	.28	.16	.47						
7	Portfolio size (ln)	3.39	1.65	-2.3	8.2	.05	.04	.17	.14	.25	.10					
8	Project interdependency	4.00	1.13	2.0	7.0	-.07	-.01	-.06	.01	.01	-.03	-.05				
9	Portfolio dynamics	3.27	1.19	1.0	7.0	.00	.04	.06	.15	-.07	-.13	.00	.18			
10	Firm size (ln)	6.99	1.91	0.7	11.5	.08	-.15	.07	.15	.04	-.03	.35	-.01	.03		
11	R&D portfolio	0.32	0.36	0.0	1.0	.08	.06	.06	-.14	.01	-.10	-.07	.05	-.13	-.04	
12	External customer	0.27	0.34	0.0	1.0	-.02	.05	.15	-.28	.08	.12	.11	-.04	-.09	-.19	.13

n = 181. M Mean, SD Standard Deviation, PPM Project Portfolio Management, PPMIS Project Portfolio Management Information Systems, SPM Single Project Management, RM Risk Management. All correlations larger than .15 are significant ($p < .05$).

5.2 Hypotheses Testing

We used hierarchical multiple regression analysis to test the hypotheses. Table 5 shows the results with PPM quality as the dependent variable. Model 1 shows that PPMIS application was positively and significantly related to PPM quality (unstandardized coefficient .22, $p < .01$). This result remained stable, even if we entered all other independent variables (moderators and controls) in model 2 (.09, $p < .05$). As expected and in line with previous studies by Teller et al. (2012) and Teller and Kock (2013), PPM formalization (.15, $p < .01$), SPM formalization (.21, $p < .01$), and risk management formalization (.09, $p < .05$) were all positively related to PPM quality. Although the effects of process formalization were strong, PPMIS application had a positive effect over and above these formalization constructs. Portfolio complexity (portfolio budget, project interdependency, and portfolio dynamics) did not significantly relate to PPM quality. Concerning the control variables, only firm size had a significant effect (-.07, $p < .01$) on PPM quality. Apparently, smaller firms and business units had a higher PPM process quality. Overall, the model explained 43 % of variance in PPM quality. Collectively, these results support hypothesis 1a that PPMIS application is positively related to PPM quality.

Model 3 to 8 show the interaction effects of PPMIS application and the moderators. We mean-centered both interaction variables and considered the moderation hypotheses supported if the interaction effect yielded a significant coefficient and the increase in explained variance was significant as well (Aiken and West, 1996). Model 3, 4, and 5 show that the interaction with all three measures of formalization was positive and significant (.05 for PPM formalization, .06 for SPM formalization, and .04 for risk management formalization, $p < .05$). This finding is in full support of hypothesis 2: PPMIS application has a stronger positive influence on PPM quality when complemented by adequate formal processes.

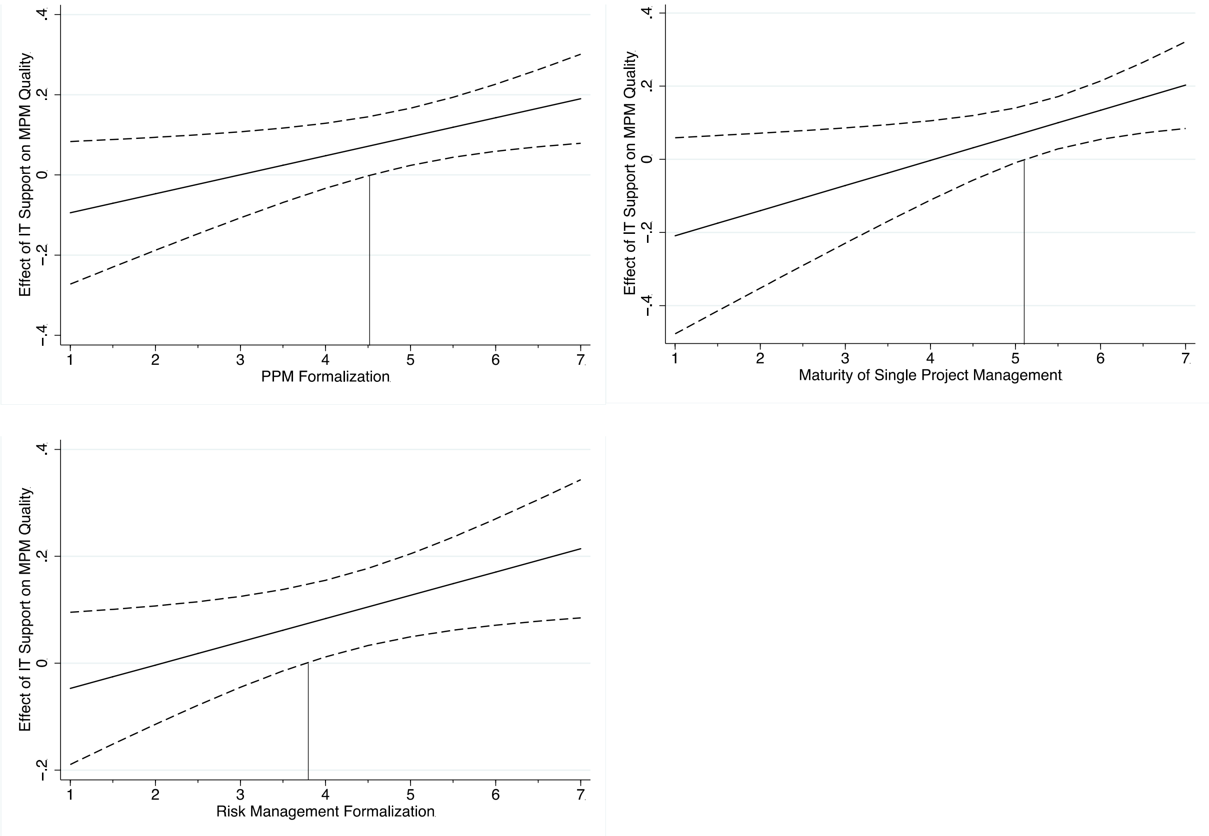
Table 5. Regression results for project portfolio management quality

	PPM quality							
Independent variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PPMIS application	.22**	.09*	.08*	.08*	.08*	.09*	.09*	.09*
PPM formalization		.15**	.16**	.14**	.14**	.14**	.15**	.15**
SPM formalization		.21**	.21**	.23**	.21**	.21**	.21**	.21**
RM formalization		.09*	.08*	.08*	.09**	.09*	.09*	.08*
Portfolio budget (ln)		-.03	-.02	-.02	-.02	-.02	-.02	-.02
Project interdependency		-.01	.00	-.01	-.01	.00	-.01	-.01
Portfolio dynamics		.03	.02	.03	.03	.03	.03	.03
Firm size (ln)		-.07**	-.07**	-.08**	-.07**	-.08**	-.07**	-.07**
R&D portfolio		.21†	.20†	.19	.19	.21†	.21†	.21†
External customer		.09	.15	.09	.09	.08	.09	.09
Interaction effects								
PPMIS application * PPM formalization			.05*					
PPMIS application * SPM formalization				.06*				
PPMIS application * RM formalization					.04*			
PPMIS application * portfolio budget						.03		
PPMIS application * project interdependency							.02	
PPMIS application * portfolio dynamics								.04
Constant	3.81**	2.53**	3.44**	3.87**	3.11**	2.63**	2.72**	2.85**
R^2	.14	.46	.48	.48	.48	.47	.46	.47
R^2 (adjusted)	.14	.43	.45	.45	.45	.44	.43	.44
Delta R^2			.02*	.02*	.02*	.01	.00	.01
F	29.21**	15.25**	14.18**	14.06**	14.14**	13.76**	13.41**	13.62**

Hierarchical OLS regression; n=181; variables in interactions are mean-centered; unstandardized regression coefficients are reported; † p<0.10; * p<0.05; ** p<0.01 (two-sided). PPM Project Portfolio Management, PPMIS Project Portfolio Management Information Systems, SPM Single Project Management, RM Risk Management

Figure 2 shows the marginal plots for all three interactions with the dashed lines representing 95% confidence intervals. The plots show for each value of the moderator the strength of the effect of PPMIS application on PPM quality, which offers a more precise picture than regular simple-slope plots. If project portfolio formalization was below 4.5, single project management formalization below 5.1, and risk management formalization below 3.8, then PPMIS application was not significantly related to PPM quality anymore (i.e., ineffective). This suggests a minimum of process formalization for IT support to work in project portfolio management. However, the effect did not become significantly negative for any value of the moderators.

Figure 2: Marginal effects for significant moderators



We did not find support for hypothesis 3, which stated that with increasing complexity the value of PPMIS for PPM quality would be more positive. None of the three variables of portfolio complexity yielded significant interaction coefficients in models 6, 7, or 8. This finding suggests that PPMIS application may be of equal value in portfolios of different sizes, different degrees of project interdependency, and different volatility.

Table 6. Regression results for project portfolio success

	Project portfolio success		
Independent variables	(1)	(2)	(3)
PPMIS application	.17**	.10*	.06
PPM formalization		.08*	.01
SPM formalization		.20**	.11†
RM formalization		.00	-.04
Portfolio budget (ln)		-.04	-.03
Project interdependency		-.05	-.05
Portfolio dynamics		.00	-.01
Firm size (ln)		.03	.05†
R&D portfolio		.20	.11
External customer		-.04	-.08
PPM quality			.44**
Constant	4.05**	2.96**	1.84**
R^2	.08	.21	.30
R^2 (adjusted)	.08	.16	.26
F	16.12**	4.53**	6.68**

Hierarchical OLS regression; n=181; unstandardized regression coefficients are reported; † p<0.10; * p<0.05; ** p<0.01 (two-sided); PPM Project Portfolio Management; PPMIS Project Portfolio Management Information Systems, SPM Single Project Management; RM Risk Management. Indirect effect of IT support on project portfolio success is .04*.

Table 6 shows the analysis with project portfolio success as dependent variable and allows testing the mediation hypothesis. First, PPMIS application was also positively related to project portfolio success, even when we controlled for all other independent variables in model 2 (.10, $p < .05$). When PPM quality was entered in model 3, this effect became insignificant. PPM quality was strongly and significantly related to project portfolio success (.44, $p < .05$), which is in support of hypothesis 1b, which stated that PPM quality is positively related to project portfolio success. Collectively, the results fulfilled the criteria for mediation by Baron and Kenny (1986). Using the bootstrap procedure suggested by Zhao et al. (2010) with 1,000 repetitions we also calculated the indirect effect of PPMIS application on project portfolio success. The indirect effect was significant (.04, $p < .05$). Overall, the mediation hypothesis 1c was therefore supported. Since the direct effect of the application of PPMIS on project portfolio success is insignificant, this type of mediation can be characterized as indirect-only mediation (Zhao et al., 2010) or full mediation (Baron and Kenny, 1986).

6 DISCUSSION

The objective of this study was to empirically test the consequences and contingencies of project portfolio management information systems (PPMIS) using multi-informant data from 181 project portfolios. To the best of our knowledge, this study is the first (1) to quantitatively demonstrate the relationship between PPMIS intensity and project portfolio success, (2) to show the mechanisms by which PPMIS affects project portfolio success, (3) to analyze the complementary effect for PPMIS of different types of PPM formalization, and (4) to investigate contingencies of the performance effects under different forms of portfolio complexity.

6.1 Theoretical Implications

The results have several important implications for research in project portfolio management. First, our results show that IT support actually matters in project portfolio environments. While many studies claim the positive effects of IT on the quality of decisions (e.g., Caniëls and Bakens, 2012), our quantitative results suggest that the application of PPMIS positively affects the performance of project portfolio management. This result even holds, if we control for several known success factors in project portfolio management such as single project formalization (Martinsuo and Lehtonen, 2007; Schultz et al., 2019b; Unger et al., 2012), project portfolio management formalization (Kock and Gemünden, 2019; Teller et al., 2012), and risk management formalization (Teller and Kock, 2013). However, we also observe that PPMIS application is by far not the strongest predictor of performance. Formal processes have on average a stronger positive impact on PPM quality and performance and explain more variance. PPMIS application is neither necessary nor sufficient, but effective if the "platform" is in place.

Second, this study sheds more light on the conditions under which PPMIS application is most beneficial. The moderation analyses uniformly suggest that the positive effect of PPMIS application depends on complementing formal processes. For example, single project management needs to be sufficiently formalized, so that the information reported for portfolio decision-making is uniform and comparable across projects. Only then can IT tools enable better decision-making. Similarly, a formal, clearly specified process for project portfolio management allows more effective utilization of PPMIS that helps, for example, in visualizing projects and their interdependencies. Also, a uniform risk understanding and clearly specified criteria for risk evaluation seem to provide the necessary conditions under which PPMIS applications can be beneficially applied. The results therefore support the suggested "fit" principle of PPMIS, which has implications for the implementation of IT tools and the degree of their possible application in specific multi-project environments. Only if the respective processes are sufficiently implemented and clearly understood, does the use of PPMIS make sense. In fact, as the marginal plots in figure 2 show, under conditions of low formalization, IT support did not have any significant effect on management quality at all. Considering the cost of implementation, the overall effect could even be negative. Although this finding corresponds to findings in other fields (Holland et al., 1999; Sumner, 1999), many practitioners often still regard IT as a panacea for their multi-project dilemmas. The large quantity and functionality of available IT solutions even amplifies this effect. While we found a positive effect on average, the results at least suggest caution.

Third, this study evaluated some important contingencies under which the performance effects of PPMIS were likely to be stronger. Portfolio complexity is an important contingency factor in project portfolio research (Martinsuo, 2013; Teller et al., 2014; Teller et al., 2012; Voss and Kock, 2013). Previous findings suggest that for example process formalization is more beneficial in PPM if the portfolio is more complex (Teller et al., 2012). We therefore expected to find similar relationships with the extent of IT support. Surprisingly, we could not find any significant interaction effects of IT support with portfolio budget, project interdependency, or portfolio dynamics. We also tested for three-way interactions with formalization but did not find any significant effects. Although non-significant findings cannot be interpreted as the absence of an effect – because the type-two error is uncontrolled and might be substantial – another explanation is possible. The positive moderation effects might exist, but additional negative moderation effects might compensate them. With increasing complexity, the information quality may also go down, because with increasing dynamism forecasts about the projects' future developments become less reliable. The usage of PPMIS will then have a lower net benefit. More research is needed to possibly identify and disentangle these effects.

Finally, by showing that PPM quality fully mediates the performance effects of PPMIS application, the study uncovers the mechanism how PPMIS help in improving project portfolio success. PPMIS are associated with and possibly improve the process quality of project portfolio management by increasing information quality, improving resource allocation and collaboration, and more generally project portfolio decision-making. The performance impact is therefore indirect, but nonetheless important. By focusing on management quality and not only eventual performance outcomes, our study therefore contributes to a better understanding of portfolio management processes (Jonas et al., 2013) and adds PPMIS application as an important factor to consider in the future.

6.2 Limitations and Future Research

The study has some limitations that need to be considered when interpreting the results, some of them give rise to future research opportunities. First, while we considered different areas of application for IT along the project portfolio management process, we did not cover every activity that can be supported. Other PPM tasks such as benefits or value management could for example also be supported by IT. We also did not explicitly compare different IT practices in their effectiveness. Correlation analyses of single items suggested similar effects on PPM quality and project portfolio success. However, future research could more specifically differentiate between the applied PPMIS. For example, some IT solutions only address narrow areas of application, while others cover many aspects of PPM and are highly integrated in the organization's enterprise resource planning system. Furthermore, out-of-the box solutions should be differentiated from highly customized solutions. Such research efforts could help to understand how PPMIS are applied in practice and to what extent they are integrated in the PPM processes. In addition, case studies could explore the value of investments in PPMIS in terms of costs and benefits and tactics for efficient implementation.

Second, PPM described the interface between the strategic management level and the operational project management level. We did not analyze the extent to which PPMIS follows a bottom-up or a top-down philosophy: while some PPMIS solutions have evolved from a single project management tool, other solutions are extensions of strategic dashboards or visualization tools. From a management perspective both approaches may coexist and complement each other, but the impact of corresponding PPMIS may differ. Thus, future research could explore the underlying philosophy of PPMIS and their impact on PPM practices in more detail.

Third, we did not consider the implementation process but only considered current practices. The implementation of new information systems comes along with several challenges that eventually determine their performance. While we could show that PPMIS require mature and formalized single project management and PPM processes, we did not analyze how the implementation of PPMIS affects these processes. Previous research has shown that often business processes are molded to fit the requirements of software and that the alignment of business processes is critical to the implementation success (Bingi et al., 1999; Holland et al., 1999; Kaiser et al., 2015; Sumner, 1999).

Finally, other potentially important aspects such as user acceptance and usability (not only for portfolio coordinators and decision-makers but also for project managers) were not yet considered in this study. Other aspects of formalization, for example the use of programme management methods were also beyond the scope of this study. Future research might explore these factors as further moderators.

6.3 Managerial Implications

Overall, the results provide some practical implications for managers who want to increase the performance of their project portfolio management system. The positive effects of PPMIS are not only anecdotal but also empirically observable in a large sample. We have shown that the application of PPMIS is (on average) beneficial assuming a certain level of process formalization. However, managers need to acknowledge that the performance impact of PPMIS is indirect. Our results show that IT can positively affect the quality of the portfolio management processes, but these processes need to be clearly defined and implemented. Introduction of IT solutions without accompanying process formalization is, therefore, likely to be pointless. Managers should therefore be cautious in trying to implement a too high degree of IT support for their PPM processes or expecting too many benefits if those processes lack the necessary maturity.

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7 APPENDIX - MEASURES

Project Portfolio Success (Second-order factor; χ^2 = 214.40 [df = 114; p < .00]; RMSEA = .071; SRMR = .068; CFI = .94)

Strategy Implementation (Cronbach's Alpha α = .85, second-order loading λ =.78)
The project portfolio is consistently aligned with the future of the company.
The corporate strategy is implemented ideally through our project portfolio.
Resource allocation to projects reflects our strategic objectives.
The implementation of the strategy is considered a great success in the organization.

Future Preparedness (α = .88, λ =.66)
We sufficiently develop new technologies and/or competences in our projects.
With our projects we are a step ahead of our competition with new products, technologies, or services.
The projects enable us to shape the future of our industry.

Portfolio Balance (α = .85, λ =.68)
There is a good balance in our project portfolio ...
… between new and old areas of application.
… between new and existing technologies.
... of project risks.

Avg. Project Outcome Quality (α = .88, λ =.68)
Please assess the *average* success of completed projects:
Our products/project results achieve the target costs defined in the project.
Our products/project results achieve the planned market goals (e.g., market share).
Our products/project results achieve the planned profitability goals (e.g., ROI).
Our products achieve the planned amortization period.

Synergy Exploitation (α = .88, λ =.70)
During the project execution, development synergies between projects (e.g., shared use of modules, platforms, technologies etc.) are rigorously exploited.
After project completion, exploitation synergies between projects (e.g. shared marketing/sales channels, infrastructure, etc.) are rigorously exploited.
We hardly ever have double work or redundant development.

Project Portfolio Management Quality (Second-order factor: χ^2 = 154.29 [df = 85; p < .00]; RMSEA = .067; SRMR = .066; CFI = 0.93)

Information Quality (α = .81, λ = .65)
A very high level of transparency characterizes our project landscape.
All relevant project status/resource information can be accessed quickly and easily.
The presentation of information to the top management level is uniform.
Project managers and line managers are constantly provided with relevant information on the overall project landscape.

Collaboration Quality (α = .77, λ = .57)

Our project teams support each other (in case of resource bottlenecks and content-related questions).

In case of problems project managers try to solve them quickly and directly among themselves.

Overall there is a very good collaboration between our projects.

Allocation Quality ($\alpha = .75$, $\lambda = .95$)

We succeed in allocating human resources to projects quickly and reliably.

We have to go through highly demanding coordination maneuvers in order to achieve a workable cross-project allocation of resources *(reversed)*.

Resource allocations are made rigorously based on the defined prioritization.

Resource promises made to project managers are kept as binding.

Termination Quality ($\alpha = .71$, $\lambda = .42$)

Unnecessary projects are identified at an early stage.

Unnecessary projects are rigorously terminated.

Once a project has been approved, we only rarely see it terminated *(reversed)*.

We don’t regard the termination of a project as a failure.

Independent and Moderator Variables ($\chi^2 = 448.30$ [df = 260; $p < .00$]; RMSEA = .064; SRMR = .068; CFI = .92)

PPMIS Application ($\alpha = .73$)

We use dedicated software for project selection and prioritization.

We use dedicated software for resource allocation and detection of bottlenecks.

We use dedicated software for the recording of employees’ competences.

We use dedicated software for risk identification and assessment in our project portfolio.

We use dedicated software to monitor project portfolio performance.

We use dedicated software for documentation and communication of lessons learned.

Project Portfolio Management Formalization ($\alpha = .93$)

Essential project decisions are made within clearly defined portfolio meetings.

Our project portfolio management process is divided in clearly defined phases.

Our process for project portfolio management is clearly specified.

Overall, we execute our project portfolio management process in a very structured way.

Single Project Management Formalization ($\alpha = .86$)

For each project a detailed project plan is developed and updated until project completion.

A standardized process model is established and practiced by all project participants.

Project managers are very familiar with our project management standards and are very well qualified for their tasks.

Each project has a steering committee and defined escalation paths.

Overall, we perform a professional single project management.

Risk Management Formalization ($\alpha = .87$)

We use a generic catalog containing all essential potential risks.

We use predefined scales to assign values to every risk level.

Different individuals responsible for risk management evaluate the same risks equally.

Individuals responsible for risk management act based on a common understanding of risk.

Responsibilities within risk management are clearly defined.

Project Interdependency ($\alpha = .82$)
A high degree of adjustment between our projects is required with respect to their scopes.
Scope changes of individual projects inevitably affect the execution of other projects.
Often projects can only be continued if the results of other projects are available.
Delays in individual projects inevitably affect other projects.

Portfolio Dynamics ($\alpha = .77$)
Our project portfolio changes significantly over the course of a year.
We often modify the project portfolio over the course of a year.