ÓBUDAI EGYETEM
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Optimized Tailoring of Agile Project Management Frameworks

From Combining Scrum and PMI towards Multivariate Optimization for Project Process Relevance Factors

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Statutory Declaration

I declare that I have authored this Thesis independently, that I have not used other than the declared sources and resources, and that I have explicitly marked all content that has been quoted either literally or by content from the used sources.

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Philipp Rosenberger

TABLE OF CONTENTS

List of Tables

List of Figures

List of Abbreviations

BPM	Business Process Management
CEO	Chief Executive Officer
CSM	Certified Scrum Master
CSPO	Certified Scrum Product Owner
ICB4	Individual Competence Baseline Version 4.0
ID	Identification Number
IEEE	Institute of Electrical and Electronics Engineers
IPMA	International Project Management Association
IT	Information Technology
MVP	Minimal Viable Product
PDCA	Plan Do Check Act
PM	Project Management
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PMP	Project Management Professional
PRINCE2	Projects In Controlled Environment Version 2
PS	Proposed Solution
SD	Standard Deviation
WBS	Work Breakdown Structure

1 Introduction

Managing projects involves versatile approaches and related skillsets. Although every project is said to be different and unique, project management frameworks like the project management body of knowledge (PMBOK) [1], ICB4 of the International Project Management Association [2], or PRINCE2 framework of Axelos [3] push toward a standardized project management approach by providing certifications and guidelines on how to act as a responsible project manager. The framework of PRINCE2 is characterized by the triple7 principle. 7 themes, processes, and principles define what to do, however, do not cover how to do it [3]. This provides freedom for project managers to choose the right methods in different kinds of project settings. ICB4 is not focusing on what and how to perform a task, but on the competencies, a project manager needs to develop for managing successful projects [2]. Soft skills like leadership and mediation are also part of this framework. Comparing the three mentioned frameworks PMBOK is with its 890.000 issued certificates [4], on the one hand, one of the most widespread and used frameworks right now and, on the other hand, the most defined and structured in regards to providing guidance about what to do, when to do it and how to do it. This rigidity of the PMBOK framework may cause the most challenges when confronted with agile development environments and is therefore the chosen framework for this research.

These well-established project management frameworks have been confronted with the trend of agile methods and cultures since the birth of the agile manifesto [5] in 2001, demanding changing requirements before following a plan, frequent deliveries and running code before comprehensive documentation. Nowadays, agile and iterative methods are used in 70% of IT projects [6].

An ambivalence between the flexibility of agile cultures and approaches and the rigidity of project management frameworks can provide freedom for experienced project managers; it can make decisions harder for inexperienced project managers [7], especially in agile-managed IT projects [8]. The fact that agile-developed IT projects are challenging for project managers is also highlighted by the CHAOS Report [9] and by Gandomani and Ziaei [10] detailing that IT projects only have success rates between 11% in case of waterfall development and 39% in case of agile development.

The problem statement of this research and Ph.D. Thesis stems from the field of tension between flexible agile methods, combined with the rigidity of project management frameworks, the uniqueness of projects and the individuality of project managers executing their project work. By investigating these topics from different angles in the form of three individual hypotheses, this research can not only improve the practice of project management but also the way management-related processes are handled. Additionally, a generically applicable model for process-based management approaches is provided, and the subjective nature of project management based on a data-driven approach is reduced.

2 Research Aims and Objectives

Based on the challenges and the problem statement described in chapter 1, the research objectives and structure can be defined. The overall aim is to improve the success of agile-developed IT projects utilizing three different approaches that provide IT project management practitioners with specific solutions for challenging tasks and areas in their projects and present focus areas for successful project management. To do so, the question of whether agile approaches can be combined with traditional project management frameworks needs to be answered as well as how such project management frameworks can be optimized using data-driven multivariate optimization algorithms. This abstract research goal may look challenging due to the individuality of different projects and project managers. However, by clearly defining three research categories tackling the objective from different angles, a step in the direction of support for the profession of project management can be achieved.

The first category investigates the compatibility of the PMBOK framework and the Scrum framework by defining critical project processes and providing solutions for these processes as well as proposing initial process relevance factors. As a result of this research category, a tailored and enriched project management approach shall be derived. This enriched project management approach can then be optimized regarding project process relevance. The multivariate optimization of relevance factors of a specifically selected set of project processes is the main result of the second research category. This part of the research project acts as a proof of concept that multivariate optimization can be applied in the field of project management. Lastly, as part of the third research category, the optimization approach is abstracted to a generic tailoring and optimization model that can be applied in many different scenarios in the field of process-oriented management approaches.

Application Scenarios

Application of the research results can be applied from two separate viewpoints as detailed in figure 1:

- From a project management-related viewpoint, solutions of critical project processes reduce the gap of compatibility between PMBOK processes and agile methods. Further, project management practitioners can follow the developed optimization approach to optimize their work, hence directly improving the health and resulting success of their projects.
- From a higher viewpoint, an abstract generic model for the optimization of process-oriented management models can be applied in many different management scenarios. This can prove that multivariate optimization can be used to provide a data-driven and thus less subjective tool to improve the way

of process-oriented working. Possible fields of application may be as small and defined as a single sprint in agile software development or as complex as a large-scale financial audit process.

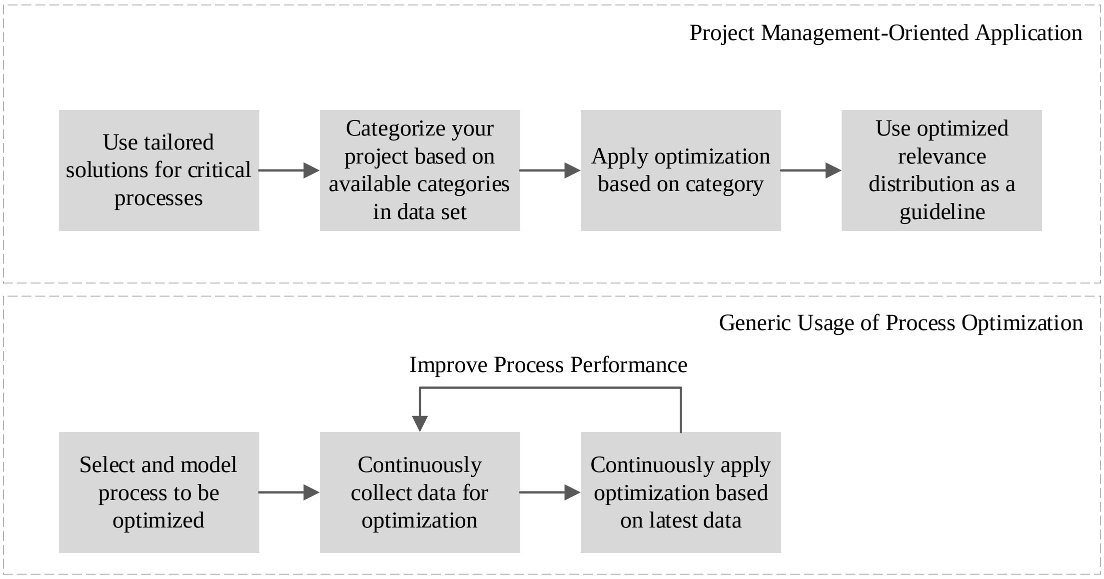

Figure 1: Application Scenarios

3 Research Strategy and Methods

To fulfill the described aims and objectives, this research follows a clearly defined three-phase strategy summarized in three hypotheses, which were transformed into specific theses based on results derived empirically.

Firstly, summarized in Hypothesis 1, literature reviews of agile approaches and the PMBOK project management framework reveal critical areas and gaps of compatibility, indicating a need for improvement and tailoring. This basic problem statement shall be investigated even deeper by analyzing and counting scientific literature to extract a matrix of initial project process relevance factors highlighting critical project processes from an additional point of view.

Based on identified critical project processes, solutions shall be developed. Their effectiveness shall be proven by a large-scale quantitative survey and detailed statistical analysis.

Hypothesis 2 shall approach the objective of data-driven optimization of the project management framework. A custom-developed data collection application shall provide a numerical basis for regression and optimization. Then, different regression methods shall be introduced, followed by an investigation of their applicability to the collected data set. To also finalize the second Thesis, the selected regression approach shall be used to successfully optimize project health for data collected with the application.

Hypothesis 3 shall abstract and even improve the steps of data-driven optimization in Thesis 2 into a generic model applicable to optimizing all kinds of process-oriented management frameworks. An exemplary application of different subcategories of the collected data set shall act as a first step toward proving the applicability of the generic model.

Figure 2 illustrates the research strategy, building upon the described three individual theses.

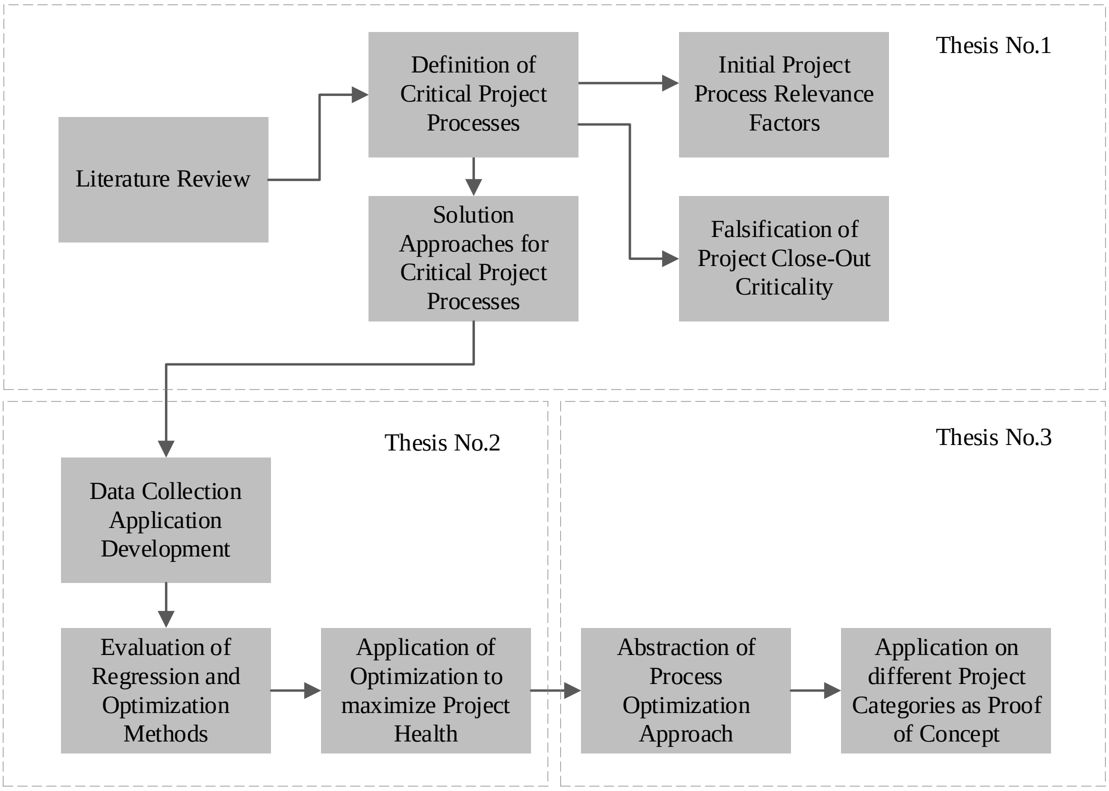

Figure 2: Research Strategy

4 Research Questions and Hypotheses

Following the clarification of the fundamental research approach, the specific research questions and suggested Hypotheses of the three research categories are defined in detail.

4.1 Compatibility of Agile Frameworks and PMBOK Project Processes

4.1.1 Research Questions

The purpose of this research category is to develop a clear understanding of whether agile frameworks like Scrum and the PMBOK version 6 project management framework consisting of 49 project processes are compatible and which project processes seem to be especially critical. Such challenging environments for project managers can manifest if the project manager is keen to strictly follow the project management framework and development teams in the project are keen to strictly follow a Scrum approach. In case of gaps in compatibility, the most critical processes shall be highlighted and described. Solutions shall be proposed to close the gaps in compatibility. The effectiveness of the proposed solutions shall be proven.

The following questions will be answered:

(Q.1.1) Where do methods, tools, values and processes of Scrum and PMBOK version 6 lack compatibility, and which solutions could fill these critical areas?

(Q.1.2) Which processes seem to be in general especially critical based on scientific literature?

4.1.2 Process and Methods to Answer Research Questions

To answer research question Q.1.1, all 49 project processes of PMBOK version 6 are analyzed and their content is compared with values, tools, and methods of the Scrum development framework, highlighting project processes that seem to be less compatible and describing the reasons for the gap in compatibility in the form of a comparison table. To propose a solution for identified gaps, deep literature research in all large scientific databases is carried out to select and describe a solution proposal for the critical processes. To verify the effectiveness and applicability of the solutions in improving the practice of agile developed projects, these solutions are introduced to project management practitioners via an online survey. Detailed statistical analysis is carried out using the software SPSS version 21 [11] to prove their effectiveness.

If project processes are not obvious in their criticality and lack of compatibility, their criticality is specifically investigated utilizing an online survey and statistical analysis.

To answer research questions Q.1.2, scientific literature is collected to solve project management-related issues. These publications are assigned to PMBOK processes based on the assumption that a majority of problem-solving literature may point towards particularly critical processes.

4.1.3 Hypothesis 1: Compatibility of Agile Frameworks and PMBOK Version 6 Project Processes

PMBOK project management framework follows a plan-driven and rigid traditional approach, whereas Scrum as the most widespread agile framework embraces change and flexibility. Identification of at least some areas that are critical for compatibility is expected. Especially planning and scheduling-related processes are less compatible, due to the flexible and constantly changing nature of agile product backlogs.

(H.1.1) Some areas of the processes of PMBOK version 6 framework show criticality in compatibility with Scrum development. This criticality can be detailed by highlighting differences in the form of a comparison table and by developing a matrix of relevance factors based on literature research.

(H.1.2) In the case of a confirmed Hypothesis H.1.1 by identified critical processes, solution approaches for identified gaps in compatibility can be proposed and their effectiveness proven.

4.2 Towards Multivariate Optimization of Project Management Frameworks

4.2.1 Research Questions

The purpose of this research category is to verify if an optimization approach using multivariate optimization techniques is feasible to improve the success of project management practitioners by delivering an optimized data-based distribution of project process relevance.

The following questions shall be answered:

(Q.2.1) How can information about success and the way project management practitioners do their work be transformed into usable data for optimization and how can this data get optimized with mathematical methods?

(Q.2.2) How do optimized project process relevance distributions look depending on defined conditions and boundaries? How can these results be interpreted?

4.2.2 Process and Methods to Answer Research Questions

To answer question Q.2.1 of this research category, an online data collection application capable of capturing distributions of project process relevance is developed. The aim is to form an input parameter for this specific optimization approach. Project health acts as a success performance indicator and forms the output parameter. Besides capturing this information, the application will also capture demographic data of survey participants and categorical information of described projects to answer future research questions and create project categories that are applied in the third research category. Further, different parametric and non-parametric multivariate regression approaches are evaluated concerning applicability and validity. The most suitable optimization approach is selected and an optimized distribution using MATLAB R2018b [12] is created. To answer question Q.2.2, different results depending on boundaries and conditions for optimization regarding validity and usefulness for project management practitioners are interpreted and discussed.

4.2.3 Hypothesis 2: Towards Multivariate Optimization of Project Management Frameworks

Because the PMBOK framework is structured in phases, project processes of different phases are not executed by project managers simultaneously. Therefore, the approach of optimization of project process relevance factors needs to happen within one specific project phase. In addition, PMBOK differentiates between continuous processes and processes only performed once. It is expected that only continuous processes of a specific project phase will build the scope for data collection and optimization.

(H.2) Optimizing project process relevance factor distributions with suitable multivariate regression and optimization methods is achievable with data collected from project management practitioners. However, the multivariate nature may need a large amount of input data to achieve robust results.

4.3 Development of a Generic Optimization Model for Process-based Management Frameworks

4.3.1 Research Questions

The purpose of this research category is to create a generic model for optimizing different kinds of process-based management frameworks. This model shall be based on the optimization result of Hypothesis 2 and contain additional improvements providing a foundation to advance the work of manifold industries by broadening the scope of the optimization approach.

The following questions shall be answered:

(Q.3.1) Can the optimization approach described in Hypothesis 2 be abstracted and enriched in the form of a process model to be usable in other applications?

(Q.3.2) Does this created generic model also work using sub-categories of the collected data?

4.3.2 Process and Methods to Answer Research Questions

To answer the questions of this research category, the steps of Hypothesis 2 are abstracted into a procedural model, facilitating the process flow chart methodology and this existing approach is enriched with additional beneficial process steps. This created model is then applied using categorically filtered data from the collected data set. Finally, different optimization results of differently filtered data sets are compared. As a proof of concept, the outcome as such is interpreted as well as lessons learned when applying the generic model.

4.3.3 Hypothesis 3: Development of a Generic Optimization Model

(H.3) As the PMBOK project management framework is merely one kind of process-oriented management framework, the multivariate optimization approach can be abstracted to a novel process model usable in various fields and applications.

5 Literature and Novelty

This chapter serves as a brief introduction to the field of research and presents relevant scientific literature structured on a research category and Hypothesis level. Based on this overview, the novelty of the different Hypotheses is explained.

5.1 Literature Review on Hypothesis 1

The field of traditional project management and agile development has been one of the most discussed and researched areas in project management in the last decade [13]. Before introducing literature covering this topic, aspects of PMBOK version 6, Scrum as the chosen agile framework for this research and agile project management as a concept, describing the combination of traditional project management including agile development, are defined.

5.1.1 Introduction to the Structure of PMBOK Version 6

PMBOK version 6 is a 700-page guideline describing 49 project processes structured into 5 phases and 10 knowledge areas, also called process groups [1]. The basic structure of PMBOK version 6 is described in table 1. It focuses on clear tasks, documentation and processes [14], rather than soft skill-related activities that are hard to evaluate. All the available processes are based on highly traditional project setups. Structured in strict phases with end-to-end planning activities in the initiation phase of a project. Naturally, this contradicts the iterative nature of agile projects. To cope with this lack of agile applicability, the PMI organization, in cooperation with Agile Alliance [15] integrated an “Agile Guideline” handbook within PMBOK, including a “PMBOK Guide Mapping” overview, which tries to map the 10 knowledge areas toward agile practices. In his evaluation, Clayton [16] gives a poor evaluation of the “Agile Guideline” handbook even calling it “non-helpful” because it fails to close the gap between agile and traditional project management approaches.

PROCESS GROUPS	INITIATING	PLANNING	EXECUTING	MONITOR & CONTROL	CLOSING
Project Integration Management	• Develop Project Charter	• Develop Project Management Plan	• Direct & Manage Project Work • Manage Project Knowledge	• Monitor & Control Project Work • Perform Integrated Change Control	• Close Project or Phase
Project Scope Management		• Plan Scope Management • Collect Requirements • Define Scopes • Create WBS		• Validate Scope • Control Scope	
Project Schedule Management		• Plan Schedule Management • Define Activities • Sequence Activities • Estimate Activity Duration • Develop Schedule		• Control Schedule	
Project Cost Management		• Plan Cost Management • Estimate Costs • Determine Budget		• Control Costs	
Project Quality Management		• Plan Quality Management	• Perform Quality Assurance	• Control Quality	
Project Ressource Management		• Plan Resource Management • Estimate Activity Resources	• Acquire Project Team • Develop Project Team • Manage Project Team	• Control Resources	
Project Communication Management		• Plan Communication Management	• Manage Communications	• Control Communications	
Project Risk Management		• Plan Risk Management • Identify Risks • Plan Qualitative Risk Analysis • Plan Quantitative Risk Analysis • Plan Risk Responses	• Implement Risk Responses	• Control Risks	
Project Procurement Management		• Plan Procurement Management	• Conduct Procurement	• Control Procurement	
Project Stakeholder Management	• Identify Stakeholders	• Plan Stakeholders Engagement	• Manage Stakeholder's Engagement	• Monitor Stakeholders' Engagement	

Table 1: Structure of PMBOK Project Processes

5.1.2 Introduction to Agile Development following the Scrum Methodology

The first basic ideas and concepts of introducing agile values into software development date back to 1986, when Takeuchi and Nonaka [17] proposed an adaptive and self-organizing development process. As an agile software development method based on the Agile Manifesto [5], the term Scrum derives from a rugby-related strategy to use teamwork to try to get the ball back into the game [18]. It is the most-used development approach with a commonness of 85% [19] and therefore the chosen framework for this research.

As a development framework, Scrum uses sprints as iterations as shown in figure 3 and thus fulfills the most important requirements for agility [20].

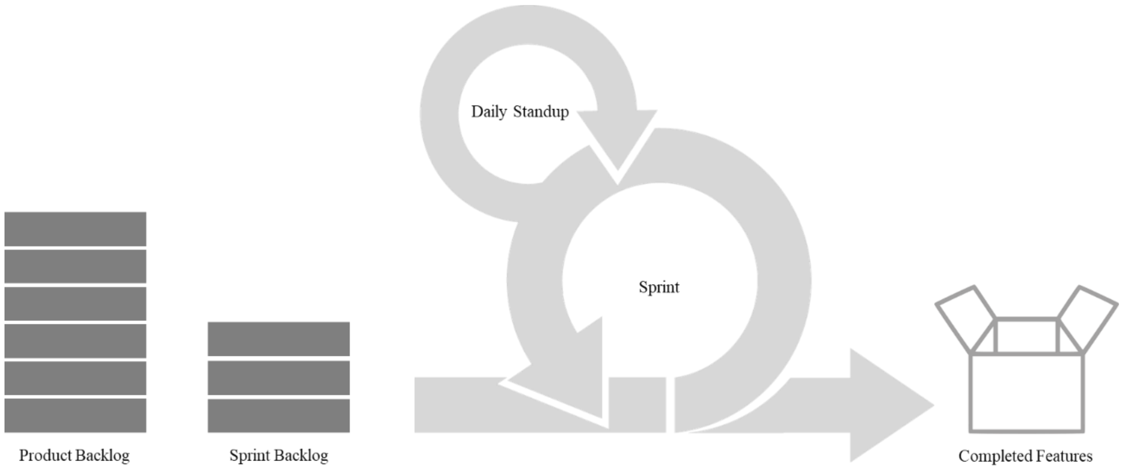

Figure 3: Scrum Development Framework

Frequently, Scrum is combined with Kanban, which is based on 4 principles [21]:

- Start using Kanban on your current status
- Implement change in increments
- Respect processes, roles and responsibilities
- Demand leadership

Scrum's main concept and idea is to accept uncertainty and change during a complex development process and not try to fit reality into a plan made early in a project. To facilitate this flexibility, certain roles like dedicated Scrum master, product owner, a self-managing development team and meeting structures like daily stand-ups, retrospectives and sprint-planning and review meetings are proposed [22].

5.1.3 Introduction to Agile Project Management

Based on this basic introduction to PMBOK and Scrum, the trending term “agile project management” [23] is introduced accompanied by a literature review aiming to combine traditional project management and agile approaches like Scrum.

Agile project management can be seen as standard project management that handles agile values and developments, by allowing flexibility in terms of features and changes, and the fact that solutions for certain problems and complexities are not known at the start of the project [24]. Due to this flexibility, iterative development enables the project team to learn along the way and constantly adapt to changes [25]. This approach is most common in the IT industry, however, it can also be applied in many other industries [26].

Based on this delimitation of agile project management from traditional project management, the scientific literature is analyzed pushing to combine and align the two approaches to serve as proof of novelty of Thesis 1.

Conforto and Amaral [27] combine agile approaches with a traditional stage-gate model, developing a hybrid framework for technology-driven projects and giving special focus on the integration of agile tools into traditional information systems used in the stage-gate model. Zhang and Shao [28] follow this concept by combining Scrum with the CMMI reference model. Siddique and Hussein [29] focus on integrating the aspect of risk management into agile software projects. Wells et al. [30] investigate organizational barriers in integrating agile concepts into traditional product and software developments in large-scale companies and recommend tailoring an approach to reduce these barriers. This tailoring is introduced as finding solutions for the discovered barriers. Fitsilis [31] lists all PMBOK processes and forms a reference to different agile frameworks like Scrum, Feature-Driven Development or eXtreme Programming. However, this article does not focus on specific project phases, does not cover PMBOK version 6 including the agile guideline and does not interpret the gaps it identifies. The conclusion of Fitsilis' work presents, that agile methods do not define everything needed to cover all aspects of project management. Specific details about the gaps between Scrum and PMBOK processes and their interpretation are not covered by this work. The approach of simple comparison without highlighting gaps in compatibility is also followed by Richter [32]. Dingsoyr et al. [33] mention 12 lessons learned in large-scale projects combining traditional project management and agile development. However, an attempt to integrate lessons into the PMBOK framework is not part of their research. Lee and Yong [34] develop their own agile project management framework and do not build on PMBOK version 6. Kuhrmann et al. [35] research the current state of practices to integrate agile approaches into traditional project management, realizing that often traditional process models get enriched with agile methods. This process-driven support is also followed in Thesis 1; however, no agile methods are integrated into PMBOK processes, but solutions are developed to cope with a critical situation when using integrated agile methods. Kontio et al. [36] cover the research field of agile practice integration. The authors develop a risk-based process model, which helps to integrate agile methods. Keith et al. [37] introduce the practice of service-orientation mostly into human-oriented processes to develop a hybrid project model. Habermann [38] investigates the interaction and compatibility of agile and traditional approaches merely on a level of 9 self-defined premises, not investigating specific PMBOK processes and providing solutions for gaps in compatibility.

5.2 Novelty of Hypothesis 1

Based on the introduction and the presented literature, this section shows that currently, no approach exists to tailor project processes of the PMBOK version 6 towards the needs of agile frameworks like Scrum. Different stage-gate-oriented approaches suggest the improvement and optimization of agile-developed IT projects [27,28], however, they do not build on the PMBOK project management framework as such. Several other publications investigate certain parts of projects, like risk management [29] or organizational requirements [30]. Often, published articles provide insight into lessons learned from a certain kind of project category or industry [28] without providing a commonly valid and understandable approach to close the gap between agile development practices and traditional project management. Tailoring as such is often applied from an organizational point of view [39] and not so much from a framework point of view.

Based on the analysis of existing literature and the identified potential research gap in providing proven solutions for PMBOK version 6 project processes, which lack compatibility with the Scrum development framework, answered research questions Q.1.1 and Q.1.2 can provide novel insights into the profession of agile developed IT projects.

5.3 Literature Review on Hypothesis 2

Hypothesis 2 covers the topic of using multivariate optimization to optimize project process relevance factor distributions of the PMBOK version 6 framework. The relevant scientific literature is reviewed and additional terminology is defined below.

Project Process Relevance

Project managers can decide individually how much focus and time they devote to certain project processes of PMBOK, as the framework only defines what should be done and how, but not how much focus to put on each task. The amount of attention and time a project manager puts into a certain project process is defined as “project process relevance” in this research project and thesis.

Project Process Relevance Distribution

Project process relevance distribution models show how project managers share their time and focus between different project processes. These distributions are the main input for the multivariate optimization approach applied in Hypothesis 2. With the data collection application, project managers are asked to distribute their individual project process relevance in a specific project of their choosing. As a project is structured in phases, starting at the initiation phase and ending at the closing phase, not all 49 project processes defined in the PMBOK are relevant at the same time. This research shall act as a proof of concept and therefore, only uses continuous project processes of the execution phase, because the main part of agile development activities happens in the execution of programming and therefore in the execution phase of projects. The advantage of this restriction is a drastic reduction of complexity in the optimization.

Project Health Factors

Project health factors are used as the output side of the optimization approach of Hypothesis 2, measuring the current “health” of a project by combining project key performance indications of budget, scope, schedule and customer satisfaction. The term “success” of a project is not used, since a lot of the data sets are related to ongoing projects, which have not achieved success yet.

After this definition of the most basic terms used in this research and especially in the research phase of Hypothesis 2, a focus on existing literature on multivariate optimization applied in the context of optimizing management frameworks is provided and has rendered the following results:

Jaafar et al. [40] facilitate multivariate methods to optimize the success of projects. Specifically, the authors developed an approach to forecast project progress using clustering and predictive analytical methods. Tariq et al. [41] applied multivariant data analysis to earned value management methods to measure project performance. Hypothesis 2 aims to increase project health. A related approach is also followed in the study of Chan et al. [42] which uses multivariate analysis to evaluate six defined project success factors. As a result, an abstract recommendation to focus on teamwork and collaborating is stated. An indication of how to practice project management work to achieve success in the recommended success factor is not presented. The papers [43,44] by Shenhar et al. and Dvir et al. with similar content and overlapping authors also follow multivariate analysis using canonical correlation and eigenvector analysis to investigate the impact on managerial variables and success measures in different project categories. Nonetheless, the focus of this research is set on highlighting specific perspectives as a result of the analysis rather than developing optimized distributions for process relevance factors.

Batarseh and Gonzales [45] investigate the applicability of data-driven approaches to improve the success of agile development processes. The focus does not lie on analyzing and optimizing the relevance of project management processes, but on predicting failures in agile-developed software with data-driven analytical and statistical methods. Chow and Cao [46] also use a data-driven approach for optimization; nonetheless, the focus of this research is based on the applicability of success factors in traditional projects in the case of agile developments. An inverted approach is chosen by Ikediashi et al. [47] in using multivariate factor analysis to indicate failure factors instead of success factors, resulting in the recommendation to improve risk management to guide clients and stakeholders toward reduced exposure to risks. Focusing on the industry of construction projects and trying to maximize the net present value of construction projects, Shagiakhmetova et al. [48] use multivariate correlation and regression analysis on 50 variants of projects.

5.4 Novelty of Hypothesis 2

Summarizing the result of the literature review relating to Hypothesis 2, it can be concluded that multivariate analysis as such is a well-established tool to analyze projects and gain an understanding of many different aspects. However, the approach of using multivariate regression and optimization to provide practitioners with a proposal about how much different tasks need to be done, in other words presenting them with optimized project process relevance factor distributions, is not presented in scientific literature. Consequently, the novelty of this approach can be assumed.

5.5 Literature Review and Novelty on Hypothesis 3

Hypothesis 3 builds on the applied optimization approach of Hypothesis 2 and abstracts this approach into a generically applicable process model by facilitating process flow chart methodology and the integration of additional process steps mitigating identified limitations during the development of Hypothesis 2.

Process flow chart modeling introduced by Frank B. Gilberth in 1921 [49], is a well-established tool in the creation of process models. Also, the concept of continuous improvement by crosschecking the success and validity, following William Deming's PDCA approach [50] is well-known in scientific and managerial practice. Hence, the approach of process modeling does not contain any form of novelty as such. However, if the approach of Hypothesis 2 can be seen as novel, an abstraction of such a novel approach using well-established methods will be novel as well.

6 Compatibility of Agile Frameworks and PMBOK Project Processes

6.1 Definition of Critical Project Processes

Based on the introduction and literature review of PMBOK, Scrum and Agile Project Management in chapter 5, a comparison of all 49 PMBOK project processes with the Scrum framework is made. As a result, 6 processes have been selected as critical and one process as questionably critical regarding the compatibility of PMBOK and Scrum. These 6 processes form the scope of further investigation. Critical project processes are defined as processes that show a gap in compatibility between agile frameworks and the PMBOK framework in this context.

The representation in table 2 comprises a side-by-side comparison in the form of a comparison matrix, highlighting identified gaps in red and the questionable process in orange:

Knowledge Area: Integration Management			
Phase	***PMBOK***	***Scrum***	***Comments** (if useful and applicable)*
Initiation	Develop project contract	Define goals in a kick-off meeting	The vision definition of a product owner in SCRUM can and should reflect a project contract.
Planning	Develop project plan	Define next sprint	Each sprint is defined in a sprint planning meeting. This definition can be seen as a project plan on a micro level.
Execution	Manage execution	Development team is managing itself	Project managers are expected to control and manage the execution of project work in all work packages. This principle of overall responsibility and control can cause a conflict with self-managing teams in SCRUM developments as a major principle of SCRUM states that development teams manage themselves without external interference within a sprint.
	Manage project knowledge	Not defined	
Controlling	Control progress	Development team and Scrum master control sprint progress	As the progress within sprints is visualized on KANBAN boards and on a product backlog level with burndown charts a project manager can facilitate this information to perform progress control.
	Manage change	Executed by the product owner in the product backlog	A well-maintained product backlog provides sufficient information for project managers to manage change.
Closing	Close Project or Phase	As Scrum is a process-oriented approach, project closings are not in focus. Phase closeouts are defined by the ending of specific Scrum sprints.	Although being not defined in Scrum and therefore not being a source for lack of compatibility, criticality could still exist. Agile-developed IT products like Apps are continuously improved and maintained after go-live. This could cause a situation of unclear and critical project close-out definitions and requirements.

Knowledge Area: Scope Management			
Phase	***PMBOK***	***Scrum***	***Comments*** *(if useful and applicable)*
Initiation	Define project goals	Defining a clear product vision is an important requirement for Scrum	The project manager can align project goals and visions with a Scrum product owner.
Planning	Plan scope management	Define the next sprint and collect requirements in the product backlog	How to manage a product backlog in a Scrum development is a key task and activity for product owners. This can be aligned with a project manager.
	Collect requirements		User Stories are requirements in agile developments and are well managed and controlled and accessible for project managers in product backlog systems
	Develop project structure plan	No long-term plan foreseen	As product backlogs are constantly changing and evolving in agile environments, a project manager can never access a complete set of requirements to form the basis for a project structure plan. Not planning long-term in uncertain projects is a key value of agile developments contradicting the planning related processes of project managers-
Execution	Validate and control content	Validation by the development team and by the product owner in sprint review meetings.	All user stories need to be defined as "done" by the development team to be ready for a sprint review meeting and are there accepted or rejected by the product owner. A project manager participating in sprint review meetings can manage and control this execution
Controlling		Controlled content by the product owner	
Closing	Not defined	Present content in a review meeting on a sprint level.	
		Released content by product owner on a sprint level	

Knowledge Area: Schedule Management			
Phase	***PMBOK***	***Scrum***	***Comments*** *(if useful and applicable)*
Planning	Define actions	Define sprint duration	Defining schedule-related actions by a project manager is a similar task to setting up the sprint approach and sprint durations by a product owner or Scrum master.
	Relate actions to each other	Define and prioritize user stories	Putting requirements or actions into relation to each other is a core activity in agile developments as well as in project management planning phases.
	Estimate duration of actions	Assign story points to sprint user stories. No estimation of other backlog user stories	Estimations of effort are a basic part of agile approaches. On a macro-level t-shirt size estimations and on a micro-level story point estimations, documented in backlog systems, can provide a good basis of information for project managers.
	Develop project schedule	Just plan for the next sprint	The development of a complete project schedule requires completeness of requirements and their duration estimations. Due to a constantly evolving product backlog, this completeness is not available for project managers in an early planning phase of a project.
Execution	Manage schedule and adapt planning	Control using Kanban and Burndown Chart	If a suitable schedule is available for project managers, the agile methods of Kanban and burndown charts can be facilitated to control and manage changes on a micro and macro level.
Controlling			

Knowledge Area: Cost Management			
Phase	***PMBOK***	***Scrum***	***Comments** (if useful and applicable)*
Initiation	Rough budget estimations	Define Minimum Viable Product as a basis for budget estimation	The requirements for a rough budget estimation in the initiation phase of a project can be covered by MVP estimations provided by the product owner.
Planning	Define cost management	Roughly estimate the number of sprints based on schedule management	Based on rough MVP estimations in the initiation phase and knowledge about team sizes of development teams, a basic plan of sprint duration and amounts of the sprint can be developed by the project manager.
	Estimate and define costs based on requirements	Estimate costs based on the number of project members, velocity and size of backlog (which is constantly changing)	Developing a detailed and reliable cost estimation in the planning phase of a project is difficult for project managers due to constantly evolving and changing product backlogs in agile environments.
Execution	Manage and control costs	Not defined	
Controlling			

Knowledge Area: Quality Management			
Phase	***PMBOK***	***Scrum***	***Comments** (if useful and applicable)*
Planning	Plan expected quality	Setup definition of done by product owner for each sprint	The role of the product owner in agile teams defines, plans, controls, and manages quality. These activities can be aligned with a project manager.
Execution	Manage quality	Continues testing in a sprint	
Controlling	Control quality	Acceptance by product owner in the sprint review	

Knowledge Area: Resource Management			
Phase	***PMBOK***	***Scrum***	***Comments** (if useful and applicable)*
Planning	Plan resource management	Not defined	
	Estimate resources for actions		
Execution	Acquire resources	Not defined	
	Develop team	The team is self-organizing and self-managing	A traditional project manager takes responsibility for team development and management. Although supported by a Scrum master and retrospective meetings, development teams manage themselves within sprints. This lack of influence during sprints can be challenging for project managers.
	Manage team		
Controlling	Control resources	Scrum Master protects the team from distractions and supports team development	Control and support are provided by the role of the Scrum master in agile environments. A traditional project manager can cooperate and align activities with the Scrum master to perform resource control to a certain extent.

Knowledge Area: Communications Management			
Phase	***PMBOK***	***Scrum***	***Comments** (if useful and applicable)*
Planning	Plan communication	Not defined	
Execution	Manage communication	High focus on communication, based on clearly defined meeting structures	Communication is a core principle and value in agile environments supported by many different roles and meeting structures like daily stand-ups and retrospective meetings for example. A project manager can participate in all these agile practices.
Controlling	Control communication	Supported by Scrum Master	

Knowledge Area: Risk Management			
Phase	***PMBOK***	***Scrum***	***Comments** (if useful and applicable)*
Planning	Plan risk management	Not defined	
	Qualitative risk analysis	Scrum Master can question risks in daily stand-up	As answering the question of current disturbances is a key element of daily standups, this aspect of risk management is slightly taken care of in agile environments. A project manager can participate in these meetings to get insights regarding potential risks.
	Quantitative risk analysis	Not defined	
	Define mitigation measures	In daily stand-up with the development team	A Scrum master and a participating project manager can support the definition and execution of solutions to potential disturbances in suitable meeting formats like retrospective meetings or daily standups.
Execution	Implement mitigation measures	Done by a self-managing development team	
Controlling	Control risks	Can be discussed in review and retrospective meetings as well as daily stand-ups'	

Knowledge Area: Stakeholder Management			
Phase	***PMBOK***	***Scrum***	***Comments** (if useful and applicable)*
Initiation	Identify stakeholder	Not defined	
Planning	Plan stakeholder engagement	Not defined	
Execution	Manage stakeholder engagement	The product owner and Scrum master involve stakeholder	External stakeholders like project sponsors and customers are actively managed by the role of product owners. Internal stakeholder like the development team is supported and managed by the role of the Scrum master. A project manager can coordinate with these two agile roles.
Controlling	Control stakeholder engagement		
Closing	Not defined	Acceptance by the product owner or sponsor	

Table 2: Comparison of PMBOK Project Processes and Scrum

Based on this overview in the form of a comparison table, a description of the identified gaps in critical processes is described below:

Critical Process "Manage Execution"

In a traditional project management approach, the project manager is responsible for all deliverables and their integration. In Scrum development teams, this integration is fully managed by the development team after approval by the product owner. No external disturbance is allowed in the integration phase within a sprint. Therefore, it can be challenging for a project manager to be responsible for the whole project while being excluded from the management during individual sprints. This challenging situation for a project manager is in some way improved by the iterative approach of Scrum and by the fact that the project manager can identify problems early after each sprint. Sometimes project managers can even cover the role of a product owner themselves. In this case, the project manager and/or product owner can manage and control the integration in each sprint review meeting. Still, continuous management of integration is not possible for a project manager, whereas executing control in each sprint is.

Questionable Critical Process "Close Project or Phase"

Project and phase closeout processes are clearly defined in PMPOK combining these three aspects [51]:

- Assurance that all project tasks are completed
- Assurance that all necessary project management processes have been executed
- Formal recognition of project completion by all stakeholders

Project closeouts, however, are not a part of agile approaches as agile development is an iterative process to develop software features as efficiently as possible. Additionally, agile developments focus on flexible product backlogs [26] resulting in a potential situation in which scope fulfillment is not a suitable criterion for project closeouts anymore, because these backlogs may change continuously.

Another indicator of criticality takes the closeout of a traditional project and the transformation towards ongoing maintenance, feature integration and improvement process into consideration. In agile frameworks like Scrum, the end of projects does not have any impact on agile practices. Nevertheless, in traditional projects, the release of project resources and the stop of management are integral parts of project closeouts. This transition between traditional projects towards an ongoing agile improvement and maintenance process could be unclear and critical. These circumstances lead to questionable criticality of project closeout processes, worth investigating individually.

Critical Process "Develop Project Structure Plan" and Process "Develop Project Schedule"

Since the criticality of project structure plan development directly implicates the development of project schedules, the description of the criticality of these two processes is merged.

The PMBOK project manager defines the structure of the whole scope of the project before starting implementation. Due to agile values of flexibility and iterations, a long-term plan is neither relevant nor desirable. The agile development team appreciates a constantly changing product backlog and focuses on the next iteration only. This short-term focus is not suited to the long-term planning of a PMBOK project manager. As a consequence of the mentioned lack of long-term planning in agile teams, difficulties also occur in scheduling estimations. Since the approach is based on a defined scope and project structure plan, a PMBOK project manager can develop a project time plan. This long-term scheduling is challenging when an agile development team merely focuses on the next sprint.

Critical Process "Estimate and Define Costs based on Requirements"

In Scrum practice, effort and cost estimations usually happen in sprint planning meetings using the planning poker methodology [52]. This cost estimation method addresses the user stories selected for the upcoming sprint. Total cost estimation in traditional project management is based on defined scope, project structure and scheduling. As this process area is already identified as critical and Scrum does not provide an agile solution for total cost estimations, it can also be identified as critical.

Critical Process "Develop Team" and Process "Manage Team"

Scrum as a development framework does not define how development teams are set up. However, as soon as a team is set up, it will demand self-management within the sprints. So, a project manager could face the responsibility for the design, development and initiation of development teams, but as soon as they are defined, the teams demand self-organization and can even be protected by a Scrum Master ensuring that a project manager, who is not defined as a relevant role in Scrum, will not interfere with the team. It may be suggested that this loss of responsibility and influence of project managers can cause challenges in culture and role understanding.

6.1.1 Conclusion

The goal of this chapter is to identify whether PMBOK version 6 is a suitable framework for agile IT projects developed according to Scrum. To answer this question, all PMBOK processes are confronted and compared to Scrum practices, values and methods, thereby highlighting potential challenges and gaps in cultures or values. The comparison shows that most of the PMBOK processes are not negatively affected by agile development or by agile culture and values. Very often, agile practices provide a valuable contribution to the goals of PMBOK processes. Challenges for agile project managers are identified in the 6 processes of:

- Manage Execution
- Develop Project Structure Plan
- Develop Project Schedule
- Estimate and Define Costs based on Requirements
- Manage Team
- Develop Team

Further, a potentially critical process is identified in the process:

- Closing Project or Phase

This conclusion provides the first part of the answer to the research question Q.1.1 "Where do methods, tools, values and processes of Scrum and PMBOK version 6 lack compatibility and which solutions could fill these critical areas?" by indicating where processes lack compatibility.

This part of the research result is supported by the peer-reviewed conference publication of Rosenberger and Tick [53], covering the identification of project processes on a knowledge area level, excluding the criticality of project closeouts at the time of this publication.

As the next step, solutions for these critical process areas are developed, and the criticality of the process "Close Project or Phase" is verified in chapter 6.3.

6.1.2 Limitation

It has to be mentioned that the selection of critical project processes is only based on an inductive research approach by comparing two frameworks in their detailed structure and content, highlighting incompatibilities from a theoretical point of view. Critical processes may differ in the project environments of various practitioners. Therefore, the tailoring approach and the proof of effectiveness do not express any claim to completeness, however, it shall act as a concept for potentially needed additional tailoring activities.

6.2 Development of Solution Proposals for Challenged Project Processes

The development of solutions for processes defined as critical is structured into two parts. The first part proposes solutions based on existing scientific literature. The applicability and effectiveness of proposed solutions are then evaluated by a quantitative online survey, further also called survey A, and a detailed statistical analysis of the result.

The second phase is a specific and detailed investigation of project closeout activities also based on an additional online survey, further called survey B, and its statistical analysis. As the Hypothesis of criticality will be falsified later in this Thesis, no particular solution was created for project closeout processes.

6.2.1 Solution for Project Process “Manage Execution”

In classically developed projects, the project manager takes sole responsibility for the project team and the execution [1]. In agile-developed IT projects according to Scrum, development teams demand self-management [22]. A Scrum master, who moderates and documents the development teams’ work and effort, supports such self-management. The resulting lack of management within a sprint shows the challenge of this particular process.

Solution Description:

Implementation of a strike systematic.

Lewthwaite [54] defines a strike as a proactive intervention of a project manager overruling the self-management of Scrum development teams. Once started, this overruling will last during the ongoing sprint. Triggers for such shifts in responsibilities need to be substantial, because strikes completely undermine the agile culture of self-management and trust. Triggers of such strike events need to be defined in detail to create a common understanding and avoid negative personal feelings as much as possible.

For example, strikes could be triggered by:

- Scrum master intervention
- Danger of non-deliverable increments at the end of a sprint
- Extreme delay, visualized in burndown-charts
- Extreme bottlenecks, visualized on KANBAN boards
- Great changes in effort estimations of user stories during a sprint in comparison to estimations in sprint planning meetings

6.2.2 Solution for Project Process “Develop Project Structure Plan” and Project Process “Develop Project Schedule”

Due to the strong relation between PMBOK Processes “Structure Plan Development” and “Project Scheduling”, these two processes are again analyzed together.

Traditional project management structures and schedules of the whole project in the initial planning phase [55]. This regards all work packages, even the uncertain future ones. There is no difference in the level of planning between certain and uncertain work packages, accepting that uncertain packages may change in the future causing the project schedule to be adapted. Scrum avoids such restructuring and re-planning by focusing only on the next sprint. This gap in the two approaches can result in major conflicts between agile developments and traditional project management.

Solution description:

A combination of hybrid macro- and micro-planning and project phase-specific backlogs.

A hybrid approach of macro- and micro-planning [56] could separate the long-term oriented culture of traditional project management and the short-term orientation of agile cultures. The project manager defines the overall scope and goals by structuring the whole project according to general practice, i.e. with a project structure plan exclusively on a macro level, accepting not knowing definite responsibilities and durations. For example, accepting rough “T-shirt size” estimations for user stories captured in the backlog. However, during actual development in development sprints, micro-planning in the form of planning poker story-point estimations can be used in sprint planning meetings to go into detail. After several sprints, a factor between actual effort and rough T-shirt size can be postulated. Consequently, project managers with experience in project delivery might get quite detailed structural estimations enabling them to develop an understanding of longer-term planning without interfering with agile sprint-oriented approaches.

The approach of phase-specific backlogs does not change the structural planning in the initial project phases as such. A project manager will create a work breakdown structure and define project phases and major milestones based on a basic specification created traditionally. All of these major project phases can be seen as “mini-agile-projects” within a traditional project. Each phase has its specific backlog, Scrum team and goal. With such an approach, the two cultures can easily coexist: at a high level, traditionally managed by a project manager, at the detailed level in a purely agile Scrum-based approach with minimal project management interference [56].

6.2.3 Solution for Project Process “Estimate and Define Costs based on Requirements”

Cost estimation in traditional projects normally consists of manpower-related costs and material-related costs. Sharing these concepts with all other projects, IT projects often develop most of their costs in relation to the workforce. Often, the actual time and effort invested by people are much more significant than investments in hardware or other material. Based on this understanding, the cost estimation can also be split into two parts:

- Material-related costs: these costs are untouched by agile development frameworks.
- People-related costs: these costs are difficult to estimate and define as complete and traditional requirements are missing in Scrum-developed IT projects, due to constant backlog changes.

Thus, focusing on people-related costs, the following two approaches could be used and integrated into PMBOK processes.

Solution description:

A combination of velocity-based estimations and MVP (Minimal Viable Product) estimations.

Velocity is a key performance indicator of agile development teams, describing the average amount of Story Points developed in each sprint, i.e. the speed at which the Scrum teams are developing [57]. Frequently, this measurement is also used in portfolio management of agile-developed project portfolios [58]. Knowing and tracking the velocity of development teams can enable an agile project manager to estimate project costs. Knowing the developers involved as well as their internal and external hourly rates, the project manager can summarize the cost of a single story point, or one average user story, based on the number of user stories developed by the team in one sprint. Hence, relying on the planning of the work breakdown structure and project scheduling and knowing the development teams and their costs and velocity, the project manager can simply multiply the planned development effort with velocity-related cost factors and develop the cost planning in the same way as the scheduling. It is important to mention that the velocity can change, which might entail a change in the cost factor. The project manager needs to keep constant track of this factor.

A fixed Minimal Viable Product is often used as the basic concept of so-called "hybrid" IT projects. It is the smallest, fastest and simplest set of features providing desired functionality without taking care of usability, design, safety, reliability and all other necessary factors of a quality system [59]. The development of such MVPs is planned and executed in a classical waterfall approach, which is easily manageable with PMBOK processes due to the high level of planning activities and rigid structure. After the finalization of the MVP increment, features and "quality" are added to the system in a strictly agile way. This hybrid approach of splitting MVPs and agile feature integration can also be used to solve cost estimation gaps in agile projects. Classical cost estimations are used to define MVP costs; no cost estimation is used for agile feature integration later on. This allows for strict separation of agile and classical frameworks, thus avoiding problems [60].

6.2.4 Solution for Project Process "Develop Team" and Project Process "Manage Team"

As the criticality of the two processes is based on the demanded self-management and autonomy of the Scrum development team, the following solution proposal is valid for both processes. According to PMBOK, the project manager is responsible for organizing and managing project resources, including human resources. The project manager can and will set up a project team and include the development teams in the initial project phase. As soon as the development team is set up, it demands self-management, i.e. there should not be active management and control from outside. This characteristic is very strong in Scrum. The teams share work and tasks internally and are even shielded by a Scrum master from outside disturbances. Consequently, the management tasks are transferred to the team itself as soon as the project management has set up a development team. This shift in responsibility can cause trouble in a project and challenge a traditional PMI project manager who needs to take overall project responsibility.

Solution description:

A combination of an implemented adapted strike system and a project manager who takes the role of a Scrum master.

As described in the first process, Lewthwaite [54] mentions a strike system as a potential compromise to share responsibility between self-managing Scrum teams and outside project managers. This approach can not only be used in project execution, but also in team-management processes. A potential trigger of strike situations, in which the project manager will pause self-management of the team and take over, could be a daily stand-up or retrospective meeting, in which problems within the development team are discussed. It is important to define clear situations within that retrospective to start a strike action. Otherwise, development teams will always hesitate to solve problems within the retrospective meeting in fear of a potential loss of self-management.

If a project manager is comfortable with merely being “inside” of a self-managing development team but accepts their demands of self-organization, he or she could take the role of a Scrum master. Within this role, the project manager can actively trigger team problem-solving in retrospective events or even on a daily stand-up basis. The realization of a critical situation and the start of a problem-solving process is often sufficient to keep projects and team structures productive, even without acting as an authority and directly managing and deciding changes [61].

6.2.5 Conclusion

Project process-specific solutions have been proposed to close the gap of compatibility between PMBOK project processes and the Scrum methodology. These solutions provide the second part of the answer to research question Q.1.1. “Where do methods, tools, values, and processes of Scrum and PMBOK version 6 lack compatibility, and which solutions could fill these critical areas?” The applicability and effectiveness of these solutions need to be investigated, followed by an investigation of the criticality of the questionable critical project closeout process.

6.3 Surveys about Current Use of Proposed Solutions and Criticality of Project Closeouts

6.3.1 Research Methodology

Two quantitative online surveys are designed to clarify two open aspects.

Survey A tests the relationship between the identified solutions based on literature research, the actual use of the solutions, and the rating of these solutions by practitioners.

Survey B cross-checks the compatibility and criticality of traditional project closeout approaches in agile-developed IT projects.

6.3.2 Sampling Procedures

Sample selection for both surveys was performed by identifying suitable candidates on the social network LinkedIn, as well as sending emails to a network of former Technical Management students at the University of Applied Sciences ‘FH Campus Wien’ in Vienna. Potential LinkedIn candidates work in IT project management in Germany/Austria/Switzerland, e.g. as a Project Director, Project Manager, or Scrum Master. Overall, 650 invitations were sent to people with knowledge in project management from April to September 2020 for survey A; around 200 invitations were made for survey B in the summer of 2021.

Current students at universities in Vienna and Budapest with previous work experience in those fields were also invited to participate in the surveys because these students are part-time students also working beside their studies and therefore being able to provide practice experience. They were included even if they did not work in management, but only had a basic knowledge of project work and project outcomes. This ensured the inclusion of participants with various levels of experience, thus allowing candidates with different perceptions of project management to contribute ensuring a wide variety of insights.

6.3.3 Questionnaire Design

The questionnaire of both surveys was produced using Google Survey and was published in German and English.

Survey A:

This survey was grouped into a demographic part and questions regarding the different solutions of project processes.

First, each participant had to answer the demographic questions. *Education level, Type of Employment,* and *Industry* were asked in a single-choice format. The participants had to choose one of 16 possible certificates when asked about *Obtained Certificates* as well as *other options* allowing the specification of other certificates.

After this, critical processes were described individually and the proposed solution (PS1 to PS5) was given. For the critical processes of “Develop Team” and “Manage Team”, only one single solution (PS2) “The combination of an implemented adapted strike system and a project manager who takes the role as a Scrum master” was presented.

Participants had to state:

- If they know about the solution;
- If they already used the proposed solution;
- If they have not used the solution yet, they were asked if they would be able to use the proposed solution.

Subsequent rating questions were based on the reply above, asking users and non-users slightly different questions for better readability. These questions were merged afterward for evaluation purposes.

If the survey participants stated to have used the solution had to state if it had enabled them to solve the problem if it had led to new problems if it had been more helpful than previous attempts of solving the problem if they would recommend the proposed solution to colleagues, and how they would rate the proposed solution in general.

If the participant stated not having used the solution before, i.e., the non-users, they had to state additionally if they thought they would be able to use the solution exactly as described. Using the same structure as for users, the participants had to describe if they thought it might be successful if it might lead to new problems, if they would recommend it to colleagues and how they would rate the proposed solution in general. In addition, the reasons for not using that solution before were inquired with a multiple-choice format of five options (such as company policies, lack of knowledge/experience, use of different methods), and the possibility to enter other reasons. For questions regarding the participant’s rating of the different proposed solutions (PS), the participant had to rate a statement on a five-point Likert scale ranging from “strongly disagree” to “strongly agree” [62]. This sequence was repeated for each of all five critical processes and their proposed solutions excluding the project close-out process.

As survey A only targeted people with knowledge about project management, an “I do not know” answer was omitted for the general and the rating questions. Generally, it is more likely that people will not answer the question, if there is an “I do not know” answer selection. Therefore, more results are invalid for statistical evaluation.

The names of the processes and proposed solutions described in survey A are shown in table 3:

PS1	Strike system for the process “Manage Project Execution”
PS2	Adapted strike system for the process area “Develop Team” and “Manage Team”
PS3	Macro- and micro-planning for the process “Develop Project Structure Plan”
PS4	Macro- and micro-planning for the process “Develop Project Schedule”
PS5	Hybrid approach MVP and velocity planning for the process “Estimate and Define Costs based on Requirements”

Table 3: Proposed Solutions for Critical Processes

All participants received the questions in the same order from “proposed solution 1” to “proposed solution 5”. All questions were mandatory and had to be answered in the same order. Consequently, it was not possible to skip any questions.

Survey B:

Survey B consisted of three parts. The first part of the online survey captured brief demographic information ensuring a correspondence of the participants to IT industry-specific demographic structure, covering

- Age distribution
- Experience in project management

The second part evaluated the impressions and satisfaction of participants working in agile-developed IT projects regarding project closeout phases and practices by covering the following 3 questions:

- Q1: Are project closeout criteria clearly defined, right from the project starting phase?
- Q2: Which factor is most relevant in triggering project closeouts? Budget, time, or scope fulfillment?
- Q3: Do you support the agile trend of fixing budget and time and adding flexibility regarding scope fulfillment as long as a “product vision” is achieved?

The third part of the survey directly evaluated the need of adapting the established closeout approaches in agile-developed IT projects using one specific choice question (Q4) to evaluate the developed Hypothesis and its alternatives. This rating was enriched by the possibility to add a voluntary statement by the participant.

- Q4: Rate the clarity of the transition process in your projects from the closed project to ongoing maintenance and ongoing feature development.

6.3.4 Demographic Profile of Respondents

Survey A

Of the 95 people who answered the survey, 66 were male, 28 were female, and 1 was unspecified. The average age was 33.3 (SD=8.24) years. A majority (84.2%) have completed university education, and half of the participants (50.5%) had more than 4 years of work experience in project management. Most participants worked in IT (32.6%), in the financial sector (13.6%), and in consulting (10.5%). The most popular PM certifications among the participants were the Certified Scrum Master (17.9%), IPMA Level D (12.6%), and the Certified Scrum Product Owner (8.4%). 83 participants completed the German questionnaire. The overall response rate was 14.6%.

Table 4 presents an overview of the sample as well as the use or non-use of the proposed solutions. Non-users were divided into two sub-groups; the first group thinks they would be able to use the proposed solution, and the second group states that they would not be able to use the proposed solution.

Variable	**n**	**%**
Demographics		
Education		
Non-academic /other	15	15.8
University	80	84.2
Work experience		
Less than 3 years	47	49.5
3-10 years	29	30.5
More than 10 years	19	20.0
Company industry		
Information technology	31	32.6
Financial sector	13	13.6
Consulting	10	10.5
Other	41	43.2
PM Certification		
Any (Agile PM, PMP, IPMA, etc.)	43	45.3
none	52	54.7
Proposed Solutions (PS)		
PS1 - Strike system for the process “Manage Project Execution”		
Know about PS	19	20
Non-Users	86	90.5
Would be able to use PS	38	44.2
Would not be able to use PS	48	55.8
Users	9	9.5
PS2 - Adapted strike system for the process area “Develop Team” and “Manage Team”		
Know about PS	15	15.8
Non-Users	82	86.3
Would be able to use PS	47	57.3
Would not be able to use PS	35	42.7
Users	13	13.7
PS3 - Macro- and micro-planning for the process “Develop Project Structure Plan”		
Know about PS	60	63.2
Non-Users	51	53.6
Would be able to use PS	29	56.8
Would not be able to use PS	22	43.1
Users	44	46.3
PS4 - Macro- and micro-planning for the process “Develop Project Schedule”		
Know about PS	48	50.5
Non-Users	66	69.5
Would be able to use PS	43	65.2
Would not be able to use PS	23	34.8
Users	29	30.5
PS5 - Hybrid approach MVP and velocity planning for the process “Estimate and Define Costs based on Requirements”		
Know about PS	34	35.8
Non-Users	71	74.7
Would be able to use PS	50	70.4
Would not be able to use PS	21	29.6
Users	24	25.3

Table 4: Survey A – Solution Applicability

Survey B:

Survey B included 85 participants. With 35%, most of the participants worked within the Austrian IT industry. 21% represented the banking and financial sector, and 10% covered consulting and training. The other participants worked in different industries like logistics, engineering, science, teaching, and sales. As nowadays many banking-related activities cover IT-related tasks and challenges, and it can be concluded that a high percentage of the survey participants worked in IT-related professions.

As presented in table 5, the distribution of age in years of the survey participants only poorly matches the age distribution of current IT industry workforce [63]. Many of the survey participants are young professionals in the IT sector who recently finished their master's program.

	Age 18-29 yrs in %	Age 30-49 yrs in %	Age 50+ yrs in %
Survey Age Distribution	80.3	12.5	7.2
Industry Age Distribution	18.7	57.4	18.7

Table 5: Survey B - Age Distribution of Participants

Regarding experience and expertise in the field of project management, participants of survey B were asked to evaluate themselves according to a Likert-Scale from 1=”very low expertise” to 5=”very high expertise”.

The results presented in table 6 show that although participants are younger than usual in the industry, most of them evaluate their project management knowledge and experience as sufficient. This positive fact balances the limitation of the different age distribution of participants, compared to the industry in general.

Project Management Experience in %	
Very Low Expertise	2
Low Expertise	12
Medium Expertise	22
High Expertise	56
Very High Expertise	8

Table 6: Survey B - Self Evaluation of Project Management Expertise

Considering all influences, it can be concluded that a high percentage of Survey B research participants were fit for answering questions of such specific IT project management-related surveys.

6.3.5 Statistical Interpretation

IBM SPSS version 21 [11] was used for data analysis of survey A and survey B.

Survey A

Exploratory factor analysis for the rating questions of all PSs was conducted to see if the PSs were rated independently or if the ratings of different PSs were dependent on each other. For better interpretability, the factors were rotated using the Varimax method with Kaiser Normalization to lower the number of variables with high loadings on more than one factor. Screen plotting was used to identify the number of factors.

Before conducting the exploratory factor analysis, a test was conducted to assess whether the data fulfilled the requirements. The Kaiser-Meyer-Olkin value is 0.876 and hence above the recommended value of 0.5 [64] indicating that the data is suitable for factor analysis. Bartlett's test of sphericity, which should be significant to perform a factor analysis, has a p-value of < 0.01 (significant if p < 0.05). Of the results obtained, five factors were extracted. With these five factors, 75.14 % of the variance can be explained. The rotated factor matrix is listed in table 7.

Rotated Factor Matrix					
	Factor				
	1	2	3	4	5
PS1 overall	**0.791**				
PS1 recommend	**0.754**				
PS1 new problems	**0.722**				
PS1 solve problem	**0.721**				
PS1 better working	**0.606**				
PS2 new problems	**0.554**				
PS4 recommend		**0.826**			
PS4 solve problem		**0.782**			
PS4 overall		**0.755**			0.311
PS4 better working		**0.717**			
PS4 new problems	0.345	**0.508**		0.321	
PS3 recommend			**0.890**		
PS3 better working			**0.856**		
PS3 overall		0.321	**0.772**		
PS3 solve problem			**0.720**		
PS3 new problems	0.394	0.389	**0.427**		
PS5 solve problem				**0.813**	
PS5 better working				**0.794**	
PS5 overall				**0.794**	
PS5 recommend			0.325	**0.791**	
PS5 new problems	0.448			**0.476**	
PS2 recommend	0.409				**0.715**
PS2 overall	0.391	0.321			**0.702**
PS2 solve problem					**0.631**
PS2 better working					**0.527**
Extraction method: principal component analysis					
all values below 0.3 are not displayed					

Table 7: Survey A - Rotated Factor Matrix

Cronbach’s Alpha values for the factor analysis were all satisfactory, with values ranging from 0.875 to 0.912 for the rating subscales and 0.946 for the combined rating scale as shown in table 8. Recommendations for an acceptable Cronbach’s Alpha value in the current literature range from above 0.70 [65] to above 0.79 [66].

Overall Cronbach's Alpha (combined scale)	**0.946**
Cronbach’s Alpha for PS1 (subscale)	0.905
Cronbach’s Alpha for PS2 (subscale)	0.875
Cronbach’s Alpha for PS3 (subscale)	0.912
Cronbach’s Alpha for PS4 (subscale)	0.912
Cronbach’s Alpha for PS5 (subscale)	0.909

Table 8: Survey A - Cronbach's Alpha Values

In addition to the factor analysis for the whole questionnaire, factor analysis and the reliabilities for every rating-subscale (every single PS) were calculated independently to verify that each subscale is represented by one factor. In each factor analysis, one factor was extracted.

Factor loadings for PS1 ranged from 0.75 to 0.88, for PS2 from 0.60 to 0.89, for PS3 from 0.59 to 0.93, for PS4 from 0.55 to 0.96, and for PS5 from 0.54 to 0.92.

To assess the general rating awarded by all participants, the mean value $\bar{x}$ was calculated for each proposed solution. The mean rating awarded for PS1 is $\bar{x}$ = 2.86 (SD=0.97), for PS2 it is $\bar{x}$ = 2.93 (SD=0.98), for PS3 it is $\bar{x}$ = 3.30 (SD=1.09), for PS4 it is $\bar{x}$ = 3.16 (SD=1.02), and for PS5 $\bar{x}$ = 2.91 (SD=1.04), respectively. Consequently, all of the PSs were rated above the neutral, neither negative nor positive, value of 2.5.

Using the Kolmogorov-Smirnov and the Shapiro-Wilk tests, the responses were tested for normal distribution. The results are presented in table 9.

	Kolmogorov-Smirnov			**Shapiro-Wilk**		
Solution Proposals	Statistic	df	Significance	Statistic	df	Significance
PS1	0.101	95	0.018	0.969	95	0.024
PS2	0.068	95	**0.2**	0.976	95	0.076
PS3	0.127	95	0.001	0.942	95	0
PS4	0.087	95	**0.07**	0.97	95	0.026
PS5	0.102	95	**0.16**	0.971	95	0.035

Table 9: Result of Kolmogorov-Smirnov and Shapiro-Wilk Tests

Both of these tests are considered significant if $p < 0.05$. When the tests are not significant, this means that the given results show a normal distribution [65]. Three distributions based on the Kolmogorov-Smirnov test show normal distribution.

After separating the ratings given by users and non-users, the test for normal distribution was performed again. Most of the PSs (PS1 users, PS2 users and non-users, PS4 users and non-users, PS5 users and non-users) showed normal distribution. Significant results (indicating non-normal distribution) could be confirmed for PS1 non-users, PS3 users, and PS3 non-users.

The t-test for equal variances was used to compare the mean ratings by users and non-users for each of the PSs in the case of normal distribution conditions. Levene's tests [67] resulted non-significant for all PS, with significance values ranging between 0,19 and 0,53. A significant difference could be detected in the mean ratings between users and non-users for PS2 to PS5, but not for PS1. Some of the data did not show normal distribution. Consequently, the Mann-Whitney U test was used instead of the t-test for significance. The mean ranks of each PS were compared between users and non-users as shown in table 10. For the Mann-Whitney U test, the asymptotic significance (considered significant if $p < 0.05$) was used [65].

PS	**Mean value users**	**Mean value non-users**	**Mean rank users**	**Mean rank non-users**	**Asymptotic significance (Mann-Whitney U test, p-value)**
PS1	3.33	2.81	60.06	46.47	0.166
PS2	3.48	2.84	63. 88	45.48	0.025*
PS3	3.66	2.98	57.53	39.77	0.002*
PS4	3.85	2.86	66.66	39.80	0.000*
PS5	3.57	2.69	66.38	41.59	0.000*

* indicates significant results ($p < 0.05$)

Table 10: Survey A - PS rating of Users and Non-Users

For PS1, this evaluation was not significant with an asymptotic significance of $p = 0.166$ while PS2, PS3, PS4, and PS5 show significant differences between users and non-users with an asymptotic significance of $p < 0.050$. All PSs were rated more positively by users than non-users.

Survey B

Survey B data analysis was much less complex than survey A as a dichotomous question needed to be answered by the survey participants to confirm or falsify the criticality of the project closeout process in agile-developed projects. Therefore, the statistical analysis was not as detailed as in survey A. The data were analyzed in a descriptive manner. In addition, two Chi-square tests were applied to analyze the distribution and frequencies of the responses in more detail.

Firstly, to test if participants who did not choose scope fulfillment in Q2 ("Which factor is most relevant in triggering project closeouts? Budget, time or scope fulfillment?") as most relevant for triggering project closeouts also agreed with Q3 stating that scope is increasingly flexible in agile projects.

As shown in table 11, the majority of 28 participants disagreed with the Q3 statement and still placed scope fulfillment as the most relevant closeout trigger. A total of 29 participants agreed with the Q3 statement and selected budget- or time consumption as the most relevant closeout trigger.

			Q3: Do you support the agile trend of fixing budget and time and adding flexibility regarding scope fulfillment as long as a "product vision" is achieved?			
			Agree	**Disagree**	**Neither**	**Total**
Q2: Which factor is most relevant in triggering project closeouts? Budget, time, or scope fulfillment?	**Scope fulfillment**	Count	18	28	1	47
		Expected	26.0	19.4	1.7	47.0
	Budget consumption	Count	10	3	2	15
		Expected	8.3	6.2	0.5	15.0
	Time consumption	Count	19	4	0	23
		Expected	12.7	9.5	0.8	23.0
	Total	Count	47	35	3	85
		Expected	47.0	35.0	3.0	85.0

Table 11: Relation of Flexibility of Scope and Project Closeouts Triggers

As shown in table 12, the responses are related to each other as the asymptotic significance is 0,001. To ensure that significance is also valid in the case of cells with an expected frequency below 5, Fischer's exact test also revealed a significance below 0.001. The majority who voted for scope fulfillment (59.6%) disagree with supporting the agile trend with additional flexibility for scope fulfillment, however, the majority of the respondents who find time (66.6%) or budget (82.6%) as the most relevant factor on triggering project closeouts agree with the agile trend of fixing time and budget with additional flexibility regarding scope fulfillment.

Chi-Squared-Test				
	Number	**df**	**Asymptotic significance (2-sided)**	**Exact significance (2-sided)**
Pearson's Chi-squared test	19,72*	4	**0.001**	<0.001
Likelihood-quotient	19.535	4	0.001	0.001
Fischer's exact test	18.034			**<0.001**
Number of valid responses	85			
* 3 cells got an expected frequency below 5. The minimal frequency is 0,53. So Fischer's exact test was applied				

Table 12: Chi-squared test of Flexibility of Scope and Project Closeouts Triggers

Secondly, table 13 details the result of relation between project management experience as defined in table 6 and responses of Q1 (“Are project closeout criteria clearly defined, right from the project starting phase?”).

			Q1: Are project closeout criteria clearly defined, right from the project starting phase?		
			Unclear and critical (1-2)	**Clear and uncritical (3-5)**	**Total**
Project Management Experience	**Low (1-2)**	Count	1	10	11
		Expected	1.3	9.7	11.0
	Medium (3)	Count	2	17	19
		Expected	2.2	16.8	19.0
	High (4-5)	Count	7	48	55
		Expected	6.5	48.5	55.0
	Total	Count	10	75	85
		Expected	10.0	75.0	85.0

Table 13: Relation of PM Experience and Criticality of Closeout Criteria

The Chi-squared test revealed independence between these two responses as the asymptotic and exact significance resulted in values far beyond 0,05 as detailed in table 14. That means that the determination of clear project closeout criteria is not dependent on experience or inexperience in project management. In 88.2% of the cases, the closeout criteria were clear and uncritical and while 87.27% of the participants with high project management experience found the closeout criteria clear and uncritical compared to the 90.9% of the respondents with short project management experience, which suggests that more experience gives a more open and critical eye on project visions and criteria.

Chi-Squared-Test				
	Number	**df**	**Asymptotic significance (2-sided)**	**Exact significance (2-sided)**
Pearson’s Chi-squared test	0,153*	2	**0.926**	1.00
Likelihood-quotient	0.158	2	0.924	1.00
Fischer’s exact test	0.155			**1.00**
Number of valid responses	85			
* 3 cells got an expected frequency below 5. The minimal frequency is 1,29. So Fischer’s exact test was applied				

Table 14: Chi-squared test of PM Experience and Criticality of Closeout Criteria

6.3.6 Findings of Survey A and Survey B

Survey A

In general, the majority of the participants did not use the PS for the problems described (69.5% to 90.5%), except for PS3 (Macro- and micro-planning for the process “Develop Project Structure Plan”), which had already been used by almost half of the participants (53.6% non-users). For all PSs, except PS1 (Strike system for the process “Manage Project Execution”), most of the non-users (up to 70.4%) think they would be able to use the PS for their projects. In general, the more participants know about the PS, the more they use it. For example, the least-known PS, which is PS1, is known by 20% of the participants and is used by 9.5%, whereas PS3, which 63.2% of the participants know about, is used by 46.3% of the participants.

As there were five PSs in the survey, the amount of five factors in the rotated factor matrix suggests that each of the factors is connected to a specific PS. All of the PSs seem to be linked to a single factor, meaning they were rated independently from each other. However, there is one item of PS2 (Adapted strike system for the process area “Develop Team” and “Manage Team”) that scores higher on the factor for PS1 than the factor for PS2, regarding the question about possible new problems when using the PS even if the value of 0.554 for that item indicates a small dependency. The reason for this dependency might be a possible contextual overlap between these two PSs, as PS1 deals with a strike system for “Manage Project Execution”, while PS2 deals with an adapted strike system for “Develop and Manage Team”. As far as the rotated factor matrix is concerned, there do not seem to be any overlaps between the other PSs (3-5), even if they all include “hybrid approaches” for different processes.

Cronbach’s Alpha test was able to demonstrate that each of the PSs as well as the whole survey produce reliable answers. The values ranging from 0.875 to 0.912 for the subscales and 0.946 for the combined scale prove the high reliability of the study design and the quality of the scales applied. Therefore, the conducted survey seems to be a suitable tool to evaluate the use of the described PSs.

The overall rating given to each PS by the participants following the Likert Scale used in the survey (1=*strongly disagree* to 5=*strongly agree*) was also calculated. As the scale has 5 values, values below 2.5 may be considered a negative rating, while values above 2.5 may be considered a positive rating. The mean values for every subscale show that all of the given PSs were rated with a positive tendency. A higher value of the mean value signifies a more positive rating of the solution. The best rating was given to PS3 (Macro- and micro-planning for the process “Develop Project Structure Plan”) with a value of 3.3/5, which is also the PS with the highest number of users, whereas the PS with the lowest number of users, i.e. PS1, received the lowest rating (2.86/5). This suggests that if a PS is used more often, it gets a better mean rating.

The t-test and Mann-Whitney-U-test were used to compare the ratings for each proposed solution between users and non-users. The mean ratings awarded to the different PSs by the users were 3.33 for PS1, 3.48 for PS2, 3.66 for PS3, 3.85 for PS4, and 3.57 for PS5, and for the non-users 2.81 for PS1, 2.84 for PS2, 2.98 for PS3, 2.86 for PS4, and 2.69 for PS5 by non-users shown in figure 4. The difference in PS1 between users and non-users was not significant, although the tendency showed the same direction with users giving better ratings than non-users (figure 4). This might explain why PSs with a higher number of users get a better overall rating.

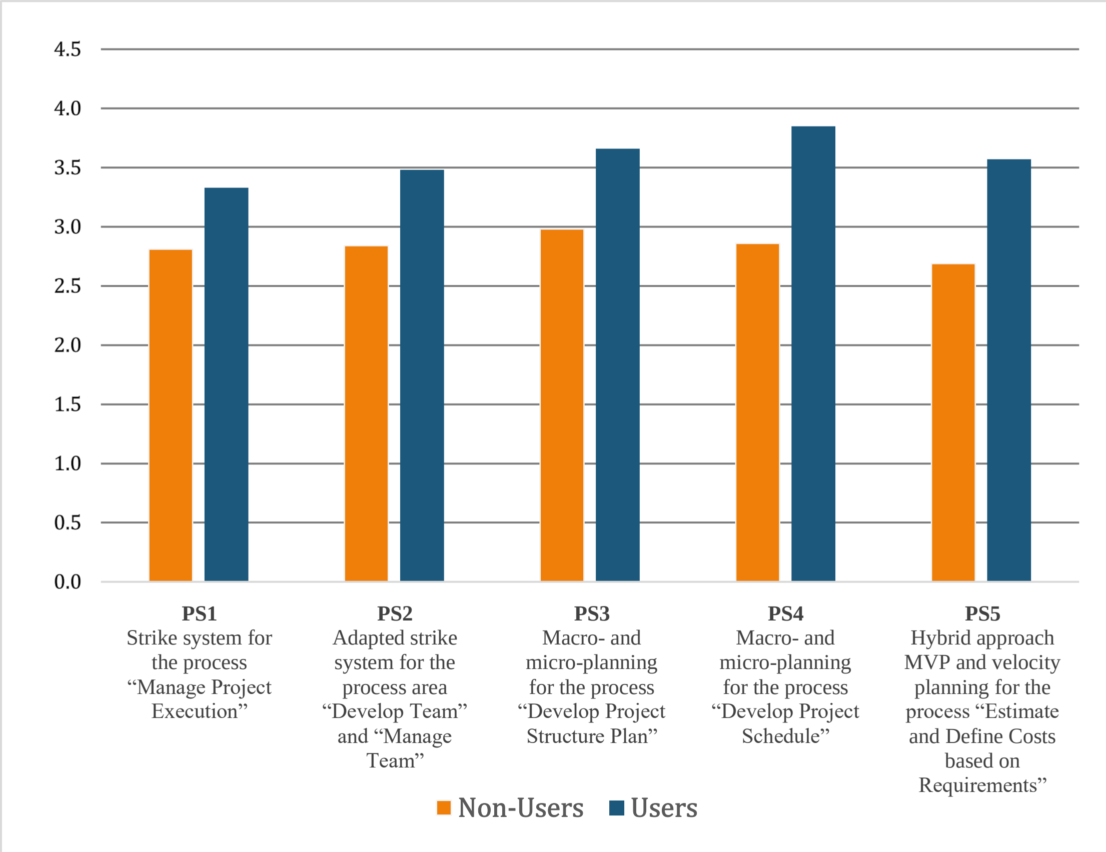

Figure 4: Survey A - Mean Ratings of PS1 to PS5 Non-Users and Users

Significant results in the Mann-Whitney-Test were found for all the PSs except for PS1, which might also be caused by the low number of users of PS1 (9 users vs. 86 non-users). If more participants used PS1, significant results compared to the other PSs would probably be generated. Generally, users tend to rate the proposed solutions better than non-users. This could mean that the proposed solutions might work better in the field than expected by non-users.

Survey B

As seen in figure 5, 66% selected a defined closeout criterion as available from the beginning in agile-developed projects. This can be interpreted as quite a good situation. It seems that the definition of how and when the closeout will happen is not a big issue in the IT industry.

As the trigger of closeouts seems to exist in agile-developed IT projects, it is investigated which element of project fulfillment is responsible for starting a project closeout phase. Also presented in figure 5, the fulfillment of scope is the biggest trigger of project closeouts. This again falsifies part of the assumption defining scope as flexible in agilely developed projects based on a limited budget or time. An additional yes or no question, including the possibility of personal statements, provides additional insight into the usage of project closeout triggers. The result of the question regarding the applicability of the magic project triangle presents itself as indifferent. 55% agree with the statement and 42% disagree. The other 3% used the personal statement option. Two out of three participants using the personal statement option mentioned that a clear project vision is enough to define clear project scope. Therefore, reaching the vision is a trigger of a project closeout phase.

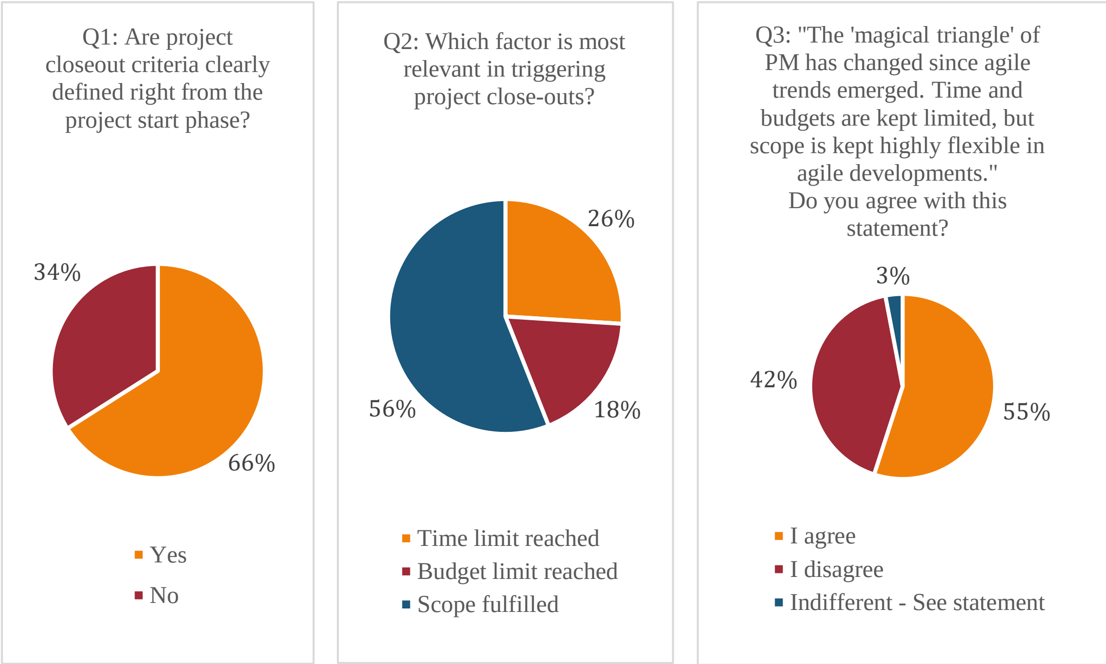

Figure 5: Survey B - Closeout Triggers

Assuming that due to an ongoing sprint-based update, process project closeout processes of traditional project management frameworks are outdated, the participants needed to rate the clarity of the switch from traditional projects to ongoing software maintenance and improvement. Thereby process criticality can be investigated. A low rate of clarity could additionally indicate criticality and the need for solutions for increased compatibility in agile-developed IT projects.

As shown in figure 6, and highlighted with a dotted box, the majority of participants indicate that the transition process is clear or at least uncritical for the success of the project and the quality of the project outcome.

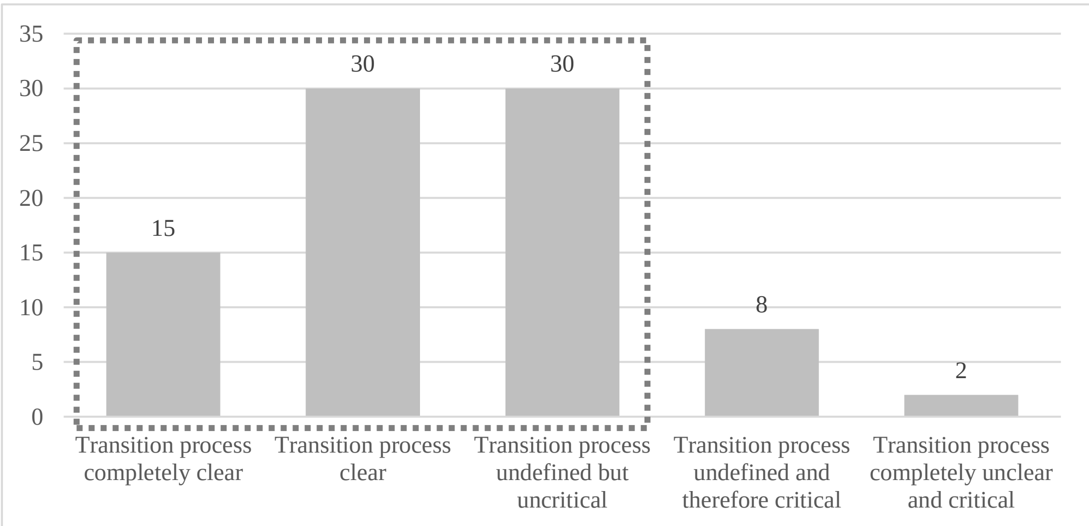

Figure 6: Survey B - Need for Framework Adaptation

In addition to this evaluation, the possibility of voluntary statements shows a specific proposal for adaptation. Eight of the twelve voluntary statements mention the possibility to clarify the transition by officially adding an "Ongoing maintenance phase" to the project, recognizing that this process is by definition not part of the traditional project anymore.

Examples of such statements are: (translated from the German language)

"I don't care how many phases a project has, I just need a point to close it and continue with an ongoing process of improvement…"

"After the last phase of the project, another phase of 'Maintenance Process' could be defined."

"If an ongoing development phase is added after the project closeout, the long-term success of projects will be increased, and valuable project resources could be made available for other tasks."

The relation between Q2 and Q3 detailed in table 11 revealed that there is a relation between these questions because Fischer's exact test was significant (p=0,001). Survey participants who supported the statement of Q3, that the agile trends are fixing budget and time and adding flexibility regarding scope fulfillment as long as a "product vision" is achieved, also stated in Q2, that scope fulfillment is not a trigger for project closeouts. This relation can indicate that there is a trend in agile developed projects moving away from the scope as clearly defined goal towards time and budget consumption as relevant closeout indicators additionally supporting the non-criticality of project close-out processes as such in agile developed projects.

The second Chi-squared test revealed, that there is no relation between self-evaluation of project management experience and the indication of project closeout criticality.

6.3.7 Conclusion of Survey A – Solution Proposals for Challenged Project Processes

The results of survey A show that a large number of participants do not know about the PSs for critical processes but still tend to give good ratings regarding usability and applicability. This finding proves the usefulness of postulated PSs. However, even if participants know about the PSs and indicate their usefulness, these still do not seem to be widely used. A reason for this lack of usage could be the missing integration into established project management frameworks, which provide certainty for project management practitioners and strengthen the need and overall research goal to tailor and adapt traditional, established project management frameworks to be used in agile developed IT projects.

These results of survey A and its analysis provide an answer to the second part of research question Q.1.1. "Where do methods, tools, values, and processes of Scrum and PMBOK version 6 lack compatibility, and which solutions could fill these critical areas?"

6.3.8 Conclusion of Survey B – Criticality of Project Closeouts

Summarizing survey B, it can be concluded that project closeout processes are not highly critical in agile-developed IT projects, due to the following results:

- The project closeout does not seem to be a real issue for practitioners in agile-developed IT projects. 66% of the survey participants knew the specific closeout criteria from the start of the project.
- The most common trigger for project closeouts is scope fulfillment. Although the scope is highly flexible in agile product backlogs, it is mentioned that a clear project- and product vision is sufficient to identify a scope suitable to trigger project closeout processes.
- Possible criticality based on unclear transitions from project end to ongoing agile improvement and maintenance processes is also contradicted, as 88% of survey participants mention this transition as at least “uncritical”.

These outcomes show that traditional project management closeout processes and approaches also work in agile-developed IT projects.

6.3.9 Limitation

A limiting factor of both surveys is the small number of participants, which is partially explained by the limited number of specialists with profound knowledge about PMBOK and agile PM. Another reason might be the low willingness to take part in surveys when contacted over social media in general, as well as the challenging situations that many companies and employees are currently experiencing due to lockdowns and COVID-19 regulations. Further, the study design of survey A did not give the option to add own solutions for the described processes, as this would go beyond the scope of this research.

A total number of participants of 85 people in survey B could be seen as a weakness of this research, especially because of the different age distribution in contrast to the industry-specific distribution. Many survey B participants come from a part-time student background and, although exact numbers are not available due to the anonymous character of the survey, a large portion of the participants relates to the University of Applied Science FH Campus Wien. However, it can also be suggested that agile practitioners may on average be younger than the industry median, because agile methods and the issues of combining agile with traditional project frameworks is a new and trending topic. This assumption could at the same time support the representability of the survey participants.

6.4 Development of Initial Process Relevance Factors

After solutions to critical project processes are defined and the criticality of project closeouts is falsified, initial process relevance factors are postulated based on detailed literature research. Project process relevance factors, as already defined in chapter 5.3, are abstract values quantifying how much focus and time project managers devote to certain project processes based on their criticality or importance for project success.

Before covering project processes, the criticality of the PMI knowledge areas is investigated, which is followed by defining six different project categories and tailoring relevance factors based on the literature research to each process in each project category. By providing such tailoring in the form of an initial indication regarding the relevance of project processes in different categories, project managers can optimize their focus on the most critical factors and worry less about neglecting less relevant project processes.

6.4.1 Scientific Literature Defining Initial Process Relevance

Whether a PMBOK knowledge area is highly relevant for a project or less relevant, is postulated by the amount of literature found covering this process or knowledge area. This indicates that processes in this knowledge area often cause problems in projects or imply a need for new solutions to improve such project processes. Relevance is initially defined by counting the amount of literature that exists related to the knowledge areas and their project processes for both agile and traditionally developed projects.

The following sections compile literature and assign statements, solutions, or critical factors to suitable knowledge areas. This compilation is the basis of the following section, in which the relevance factors of PMBOK processes are chosen based on the frequency of applicability in the knowledge areas listed below. It has to be mentioned that the quality and therefore weight of the statements and publications is subjective. That’s why an objective qualification has not been performed. Only the number of identified publications serves as input to these initial relevance factors.

Knowledge Area: Integration Management

- Pradhan et al. [68] mention in their article that project planning and scheduling are a major success factor for projects, supporting higher relevance of the process “Develop Project Plan”.
- Lu et al. [69] suggest that “a clear expression of demands by the customer is vital to the success of the project.”, indicating that higher relevance should be applied to the process “Develop project charter”.
- Mohagheghi and Jorgensen [70] detail unclear requirements as a special success factor for large projects. This strengthens the importance of a clear project charter.
- In the book “Information Technology Project Management” by Marchewka [71], poorly defined requirements are mentioned as important success factors again strengthening the definition of an exact project charter.
- Management and controlling during the actual work in the project are highlighted by Wieczorrek and Mertens [72] supporting the relevance of the process “Direct and Manage Project Work”.
- A clear definition of goals is stressed in the article “Critical success aspects in project management: Similarities and differences between the construction and the software industry” [73] supporting the high relevance of the Project Charter Definition process.
- A whitepaper of Hays Consulting [74] mentions realistic project planning as a critical success factor, particularly in agile projects. This slightly contradicts the culture of agile projects in not planning too much but focusing on delivering code. Yet, it still strengthens the process of developing a project management plan in agile projects, even if it is merely sprint-related or epic-related planning.

Knowledge Area: Scope Management

- Wiltscheck [75] describes the precise definition of the project scope as a major success factor for projects.
- Shuanqquin et al. [76] describe requirements as highly important, especially for IT projects, supporting the process area of scope management, and the process of “Collect Requirements
- In Altahooh’s and Emsley’s article about the outcomes of IT projects [77] a collection of high-risk factors for IT projects is presented. One major factor is unclear requirements applied to the process “Collect Requirements”.

Knowledge Area: Time Management

- As described in Knowledge Area Scope Management, Altahooh and Emsley [77] also identify unrealistic time plans as a major risk factor for projects.
- Taba and Khatavakhotan [78] portray successful time management as especially difficult in IT projects.
- Coolman [79] interviews Jazmin Truesdale, CEO of Mino Enterprises, about the importance of realistic time planning providing details about a successful approach to achieving such time goals.

Knowledge Area: Cost Management

- Remaining within budget is described as one of the major challenges in IT projects by Altahtooh and Emsley [77].
- Keeping cost control is stated to be a critical success factor, especially in government IT projects [80].

Knowledge Area: Quality Management

- Besides time management, quality management is mentioned as an important characteristic for IT projects in Taba’s and Khatavakhotan’s article [78].

Knowledge Area: Resource Management

- Ineffective team staffing is described as a major cause of problems in software projects [68].
- Clear clarification of duties, powers responsibilities, and interests are identified as major success factors in Lu et al.’s article [69] about failure factors in small and medium software projects.
- Monitoring, controlling, and organizing team members is depicted as a key success factor in Pakistani IT projects [80].
- The education of project leaders is described as a proposed solution to improve failing projects [81].
- The lack of project team members with the right skills, abilities, and decision-making competence is mentioned as a key failure criterion in Marchewka’s book about IT project management [71].
- The experience of the project manager is particularly stressed as a key success factor in the book “Management of IT projects” by Wieczorrek [72].
- Wiltschek [75] also mentions the need for a capable project team.

- Commitment to teamwork is mentioned by Hays Consulting [74], which is especially applicable in agile project cultures.

Knowledge Area: Communication Management

- Lu et al. [69] outline that communication in teams is highly relevant, particularly in small and medium-size software projects.
- "Sharing information in a sufficient way" is described as a key success factor for IT projects by Shuanqqinet al. [76].
- The article "Is a Challenged Project One of the Final Outcomes for an IT Project?" [77] lists bad communication as a risk factor in IT projects, which is not defined further.
- Besides improper staffing, poor communication is as well listed as a failure criterion by Marchewka [71].
- Including external communication experts to improve communication effectiveness is described as a way to improve project success. Rarely does lack of qualification trouble projects; it is rather the lack of efficient communication [82].
- Tom Atkins, a founder of the company Quarry House, mentions poor communication as the most important obstacle to project success [79].
- Data analysis for Brazilian IT projects shows that lack of communication is considered a determinant factor in the failure of IT projects because communication is linked to how the organization interacts and how the organizational culture of the company is established [83].

Knowledge Area: Risk Management

- Brugger [84] mentions sufficient risk analysis as a key factor to perform plausible decision-making. He states that wrong solutions are often used due to the lack of proper risk analysis including the definition of probabilities and risk potentials.

Knowledge Area: Procurement Management

- No literature has been identified, highlighting project procurement and its associated processes as especially critical.

Knowledge Area: Stakeholder Management

- The effect of project stakeholders not being linked closely to a small or medium-size IT project is described as little by Lu [69]. Yet, it is stated that in large-scale IT projects, the situation might be different.

Summary:

Without considering different project categories yet, an initial picture of the relevance of knowledge areas can be drawn by counting the number of relevant passages in the identified literature. It is assumed that highly relevant areas are mentioned more often in scientific literature in terms of critical processes or potential solutions. Counting all literature passages and assigning them to their knowledge areas creates the distribution presented in figure 7.

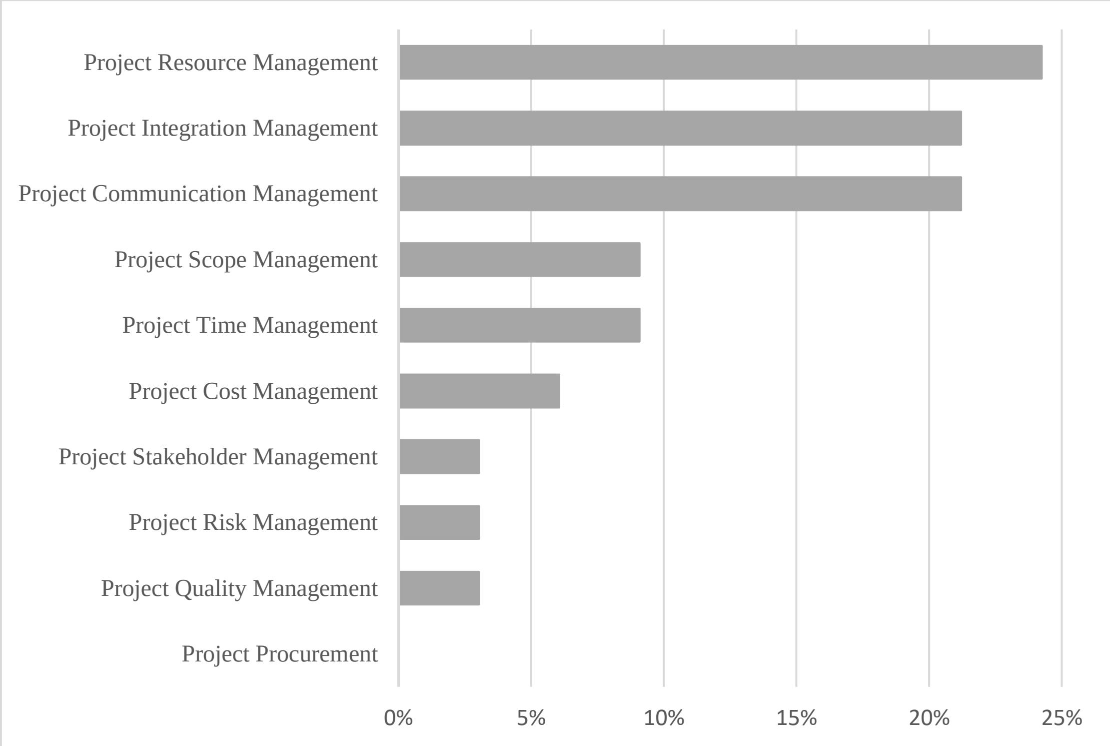

Figure 7: Knowledge Area Relevance

Three knowledge areas seem to be highly relevant, together covering approximately two-thirds of the mentioned literature: the management of communication, resources, and integration.

6.4.2 Project Category Specific PMBOK Process Relevance Factors

Based on an understanding of the applicability of knowledge area-based literature, specific relevance factors will be postulated at a project process level. A weighting factor of "1" describes minimal relevance, and a weighting of "5" maximum relevance for IT project managers.

In addition to the definition of relevance factors on a project process level, tailoring in the form of six different project categories is applied where applicable. As it is widespread and extensively used as a reference in scientific papers, the CHAOS report by the Standish Group [9] forms the basis of the definition of project categories. In this report, IT projects are clustered into two main groups:

- Classical (like waterfall, V-model, or spiral model-developed) IT projects
- Agile (like Scrum-developed) IT projects

Each of these two groups is again divided into three subcategories:

- Small-scale IT projects
- Intermediate-scale IT projects
- Large-scale IT projects

The tailoring approach of this research will reuse these CHAOS report categories as a reference. Processes with weighting factors of 4 and 5 points are highlighted in red to visualize high relevance and factors of 3 are highlighted in orange for medium relevance areas as shown in table 15.

Knowledge Area	ID	Process	Small Classical	Medium Classical	Large Classical	Small Agile	Medium Agile	Large Agile
Project Integration Management	1.1	Develop Project Charter	4	4	4	4	4	4
	1.2	Develop Project Plan	4	4	4	3	3	3
	1.3	Direct and Manage Project Work	4	4	4	3	3	3
	1.4	Manage Project Knowledge	1	1	1	1	1	1
	1.5	Monitor and Control Project Work	1	1	1	1	1	1
	1.6	Perform Integration Change Control	1	1	1	1	1	1
	1.7	Close Project or Phase	1	1	1	1	1	1
Project Scope Management	2.1	Plan Scope Management	1	1	1	1	1	1
	2.2	Collect Requirements	5	5	5	4	4	4
	2.3	Define Scope	5	5	5	4	4	4
	2.4	Create WBS	1	1	1	1	1	1
	2.5	Validate Scope	1	1	1	1	1	1
	2.6	Control Scope	1	1	1	1	1	1
Project Time Management	3.1	Define Activities	2	2	2	2	2	2
	3.2	Sequence Activities	2	2	2	1	1	1
	3.3	Estimate Activity Resources	2	2	2	1	1	1
	3.4	Estimate Activity Durations	2	2	2	2	2	2
	3.5	Develop Schedule	2	2	2	1	1	1
	3.6	Control Schedule	2	2	2	1	1	1
Project Cost Management	4.1	Plan Cost Management	1	1	1	2	2	2
	4.2	Estimate Costs	1	1	1	2	2	2
	4.3	Determine Budget	1	1	1	1	1	1
	4.4	Control Costs	2	2	2	3	3	3
Project Quality Management	5.1	Plan Quality Management	1	1	1	1	1	1
	5.2	Manage Quality	2	2	2	2	2	2
	5.3	Control Quality	1	1	1	1	1	1
Project Resource Management	6.1	Plan Resource Management	1	1	1	1	1	1
	6.2	Estimate Activity Resources	1	1	1	1	1	1
	6.3	Acquire Resources	1	1	1	1	1	1
	6.4	Develop Team	5	5	5	4	4	4
	6.5	Manage Team	5	5	5	4	4	4
	6.6	Control Resources	4	4	4	3	3	3
Project Communication. Management	7.1	Plan Communication Management	1	1	1	1	1	1
	7.2	Manage Communications	5	5	5	5	5	5
	7.3	Monitor Communications	5	5	5	5	5	5
Project Risk Management	8.1	Plan Risk Management	1	1	1	1	1	1
	8.2	Identify Risks	1	1	1	1	1	1
	8.3	Perform Qualitative Risk Analysis	2	2	2	2	2	2
	8.4	Perform Quantitative Risk Analysis	2	2	2	2	2	2
	8.5	Plan Risk Responses	1	1	1	1	1	1
	8.6	Implement Risk Responses	1	1	1	1	1	1
	8.7	Monitor Risks	1	1	1	1	1	1
Project Procurement	9.1	Plan Procurement Management	1	1	1	1	1	1
	9.2	Conduct Procurements	1	1	1	1	1	1
	9.3	Control Procurements	1	1	1	1	1	1
Project Stakeholder Management	10.1	Identify Stakeholders	1	1	1	1	1	1
	10.2	Plan Stakeholder Engagement	1	1	2	1	1	2
	10.3	Manage Stakeholder Engagement	1	1	2	1	1	2
	10.4	Monitor Stakeholder Engagement	1	1	2	1	1	2

Table 15: Project Category Specific Relevance Factors

6.4.3 Interpretation of Factor Deviations in Different Processes and Categories

Ad Process 1.2:

A proper project plan is considered important in scientific literature as a majority of articles cover this knowledge area in some form. This importance creates a higher initial relevance factor that is kept in all classical project categories. As agile projects do not follow a classic project plan, only plan in sprints and sometimes in epics or other major releases, project plans are seen as slightly less relevant in these categories.

Ad Process 1.3:

Management of project work is initially defined as a higher relevance factor. As project sizes increase in classical project categories, the importance of the "directing" part of project work will increase. Due to self-organizing development teams in agile projects, the need for managed and directed work is stated to be less relevant.

Ad Processes 2.2 and 2.3:

The definition of a clearly understood goal is part of many articles resulting in high relevance in the processes of project charter, scope definition, and requirement collection. In agile projects, the collection of requirements is slightly less weighted because requirements in the form of user stories are collected during the whole project phase and not only during the beginning of the project like in classical developments. Consequently, faults or weaknesses in requirement collection processes in agile projects can be more easily corrected in upcoming sprints.

Ad Process 3.2, 3.3, 3.5, and 3.6:

Sequencing and estimating activities, as well as scheduling, are more important in classical projects than in agile projects. In classical projects, these planning processes determine the entire project plan and all following activities. In agile projects, sequencing and estimations are done regularly on a sprint basis. This does not imply that activities are less important in agile projects, but that agile approaches implement more change and adaptation options later in the project to correct early mistakes, thereby reducing the criticality.

Ad Processes 4.1 and 4.2:

Handling costs in agile projects can be stated as more critical than in classical projects since no fixed scope is defined in agile projects. Agile project managers can only plan current product backlogs, which are constantly changing. This flexibility can be seen as an advantage, but also as a challenge for agile project managers. Due to the increasing complexity of project size and duration, large projects can also be considered more challenging than smaller projects. Based on the literature research, only a few articles focus on cost-related processes, so the general relevance is not particularly high, yet it differs significantly in the project categories.

Ad Processes 6.4 and 6.6:

Many different scientific sources state the importance of suitable and high-performing resources, leading to generally high relevance factors throughout all processes.

The most difficult and thus most relevant process could be the development of a team and team culture. It requires a lot of patience, experience, and finesse to lead a project team and bring out the best in everyone. Hence, relevance factors gain significance in processes with increased leadership interaction.

Ad Process 10.2, 10.3 and 10.4

Merely one scientific source mentions stakeholder management. Nonetheless, it should only be neglected in small and medium-sized IT projects. Large projects were not analyzed in this paper. As the complexity and number of stakeholders in large projects increases, it can be suggested that the relevance of stakeholder engagement rises in large-scale classical projects as well as in large agile developed projects.

6.4.4 Conclusion

Based on literature research identifying and listing critical, relevant, and troubling areas in IT projects, the knowledge areas of integration management, scope management, resource management, and communication management have been identified as being more relevant for project success than the other knowledge areas since they receive more scientific attention in the literature. Building on the assumption that not all knowledge areas and hence not all PMBOK project processes are equally relevant, an initial definition of relevance factors for all processes has been developed in table 15. Based on the trend regarding agile frameworks in IT project management, it can further be assumed that these relevance factors differ between project categories. For example, the definition of a detailed project plan in a large waterfall-developed IT project will be more relevant and significant than in a small agile-developed IT project. To do justice to the different project categories, tailoring of relevance factors has been implemented as well in the form of six project categories.

Using scientific literature as well as project categories as a basis, relevance factors for all 49 project processes in all six project categories have initially been defined. In many processes, no differences between the project categories have been applied yet due to the lack of relevant indications. However, for some processes, considerable differences in relevance factors have been identified and the reasons for these differences are detailed in chapter 6.4.3. Summarizing these unique category-specific characteristics, agile project processes frequently seem to require less attention by project managers – such as in processes of requirement management or team management. As a preliminary conclusion, it can be summarized that four areas of project processes are especially relevant for project success, which do not differ significantly from the six tailored project categories. It is important to emphasize that these initial relevance factors have not yet been scientifically proven; this is a first approach towards giving IT project managers an indication of which elements of PMBOK may be more important than others. The result of this initial relevance factor development answers the research question Q.1.2 “Which processes seem to be in general especially critical based on scientific literature?”

6.5 Thesis 1 based on Hypothesis 1

In the following, the two parts of Hypothesis 1 are discussed.

(H.1.1) Some areas of the processes of PMBOK version 6 framework show criticality in compatibility with Scrum development. This criticality can be detailed by highlighting differences in the form of a comparison table and by developing a matrix of relevance factors based on literature research.

A comparison table detailed all PMBOK processes, compared them to Scrum methods and agile approaches, and identified 6 critical project processes and one potentially critical process. A matrix of relevance factors based on deep literature research showed high relevance in several project processes. These two results and their interpretation confirm Hypothesis H.1.1.

(H.1.2) In the case of a confirmed Hypothesis H.1.1 by identified critical processes, solution approaches for identified gaps in compatibility can be proposed and their effectiveness is proven.

Solutions for 6 critical processes have been selected based on literature research, their application, and their effectiveness investigated and proven by the use of quantitative statistical analysis. The criticality of one potentially critical project process has been falsified by the use of quantitative statistical analysis. Hypothesis H.1.2 can be confirmed.

Hence, the two parts of Hypothesis 1 are verified and can be summarized in Thesis 1.

Thesis 1: Compatibility of Agile Frameworks and PMBOK Project Processes

I conducted a comparative analysis on PMBOK and SCRUM methodologies, based on which I developed a comparison table detailing PMBOK project processes, putting them in contrast to Scrum methods and approaches and identifying 6 critical processes and one potentially critical process regarding compatibility. I supported this problem statement of incompatibility with the creation of an initial project relevance factor matrix, highlighting processes of high criticality in the project management practice. I falsified the criticality of the potentially critical process and proposed applicable and effective solutions for all other critical processes. These combined results improve and tailor the PMBOK version 6 framework for handling agile methods.

My own publications supporting Thesis 1 are [85,86,53,87,88].

7 Towards Multivariate Optimization of Project Management Frameworks

7.1 Introduction

Thesis 1 described the compatibility of agile frameworks and PMBOK as a traditional project management framework. This second research phase, later summarized by Thesis 2, covers an approach to improve project health as described in chapter 5.3 from a "how to work" as a project manager rather than from an agility perspective.

Chapter 5.3 introduces the concept and terminology of project process relevance factors as factors defining the importance of a specific project process. Hypothesis 2 takes this approach further based on the assumption that the project manager will mainly focus on project processes with high relevance factors. This thought serves as the basis for Hypothesis 2. The goal is to research objectively where successful project managers put their focus and if the mathematical approach of multivariate optimization can be applied to define an optimized project process relevance factor distribution.

Trying to answer such a question and defining one single optimized solution may be seen as critical because projects and project managers are highly individual and subjective and therefore not suitable for comparison. A project manager developing software for air traffic navigation may focus much more on risk management than a project manager developing an online game for a small startup software company for example. Such individuality is justified and allowed in the following approach of Hypothesis 2. It is not a goal of this research phase to define how much focus project managers should put on different project processes. However, the goal is to provide a data-based indication of where successful project managers do put their focus. Which processes execute successful project managers a lot and which barely? And provide proof that multivariate optimization is an applicable method to achieve such results.

As mentioned, the desired goal is to maximize project success. However, project success is a state at the end of a project defined in literature as "reaching the end of the project in time, budget and scope" [89]. Project managers are only active and influence a project during its execution. This is why not project success is the goal of optimization but project health, as defined in chapter 5.3, along the phase of project execution. In addition to the mentioned three parameters of time, scope, and budget, the output of project health has been enriched following the concept of Wyngaard et al. [90] with "customer satisfaction" as a fourth parameter. Kerzner [89] also mentions the acceptance by a customer as an additional relevant success criterion. This is especially relevant for agile-developed projects as timelines and scopes are often seen as flexible.

The approach of converting multiple responses to a single response is based on the idea described by Khuri and Conlon [91]. However, a complex vector-distance-based model did not seem necessary for the simple goal of combining result variables. Consequently, an amalgamation approach, as in signal noise ratio research [92], was selected. Constrained optimization, defining one single output factor as leading and the others as constraints [93] is not used because all project health factors are considered equally important.

7.2 Research Methodology

The first step in this research phase is to collect data about projects from project management practitioners in the form of project process relevance factor distributions as input variables and project health indicators as output variables. As adjusting these distributions can be challenging for survey participants, a custom-developed data collection application is developed. Based on this collected data and an initial data cleaning and analysis, different regression and optimization methods are evaluated for applicability. As the last step toward a proof-of-concept result for optimization boundaries and conditions are defined.

7.3 Project-specific Data as Basis for Optimization

Since many of the survey participants are currently working on a specific project, a project phase was selected. Although planning as a phase is mentioned as a critical success factor [94], the execution phase, which can have quite a long duration comprising the bulk of the project work [95], was selected for this research. The execution phase contains 10 processes, 8 of which are continuous, and the scope of the optimization approach. The advantage of this restriction toward one project phase is a drastic reduction of complexity in the optimization.

Below, a brief description of continuous processes and their IDs of the selected execution phase can be seen [1]:

- **P1 = Direct and Manage Project Work -** the process of leading and performing the work defined in the project management plan and implementing approved changes to achieve the project objectives.
- **P2 = Manage Project Knowledge** - the process of using existing knowledge and creating new knowledge to achieve the project objectives and contribute to organizational learning.
- **P3 = Manage Quality -** the process of translating the quality management plan into executable quality activities that incorporate the organization's quality policies into the project.
- **P4 = Develop Team** - the process of improving competencies, team member interaction, and overall team environment to enhance project performance.
- **P5 = Manage Team** - the process of tracking team member performance, providing feedback, resolving issues, and managing team changes to optimize project performance.

- **P6 = Manage Communications** - the process of ensuring timely and appropriate collection, creation, distribution, storage, retrieval, management, monitoring, and the ultimate disposition of project information.
- **P7 = Implement Risk Responses** - the process of implementing agreed-upon risk response plans.
- **P8 = Manage Stakeholder Engagement** - the process of communicating and working with stakeholders to meet their needs and expectations, address issues, and foster appropriate stakeholder involvement.

7.4 Sampling Procedures for Optimization Data Collection

Sample selection was performed by disseminating the invitation for the participation of project management practitioners on social networks like LinkedIn or Facebook, sending emails to a network of former Technical Management students at the University of Applied Sciences “FH Campus Wien” in Vienna and addressing suitable participants directly in networking events and conferences. All persons previously or currently involved in project management in different roles were able to participate. An estimated 600 invitations sent for 22 months led to 109 valid survey completions.

7.5 Questionnaire Design

The actual data collection was implemented using a custom-programmed data collection cloud-based web portal [96] since out-of-the-box survey software solutions did not provide the specific capability of distributing relevance factors.

Link: https://agile-projects-survey.herokuapp.com/home

Besides using project process relevance distributions as the input parameter and project health factors as the output parameter, the survey participants also entered characteristics of their background and projects.

7.6 Respondents

Of the 109 people who answered the survey, 76% are male and 24% are female. 40% of the participants are aged between 20 and 30 years, 39% are between 30 and 40 years, and the remaining participants are older. A majority of 89% have completed university education, and half of the participants (49%) are experienced as project managers or project sponsors. Most participants (52%) work in management and business, IT, and finance-related industries.

67% of the participants work with agile or at least hybrid project management frameworks.

7.7 Initial Statistical Analysis

A basic statistical analysis of parameters collected in the data collection is shown in figure 8 and table 16 below. The different project process relevance factors P1 to P8 serve as input factors and the project health indicator as a normalized value based on the four individual health factors of *scope*, *budget*, *schedule,* and *customer satisfaction* as output factor.

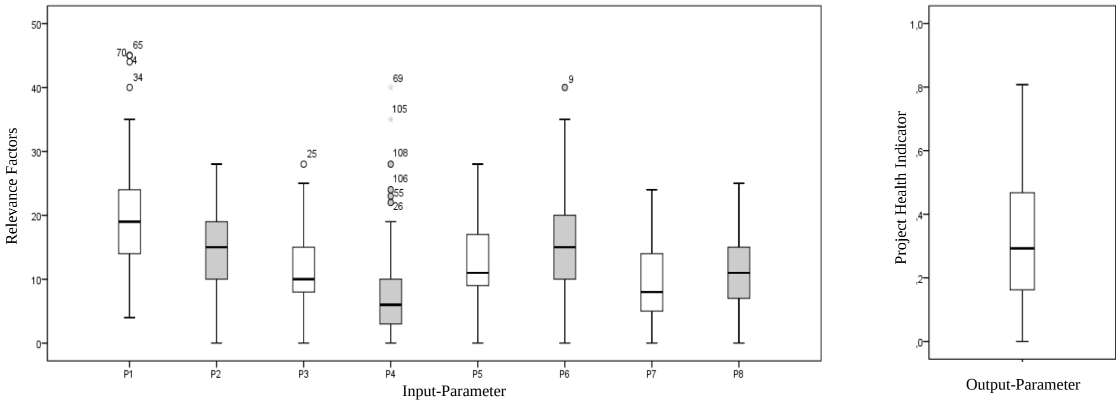

Figure 8: Box Plot Statistics for Input- and Output-Parameter

			P1	P2	P3	P4	P5	P6	P7	P8	Output
		lower whisker	4								
Percentile	5		6.5	5	2.5		4	1.5		1	0.05
	10		10	5	5		5	5	2	4	0.08
	25	1st quartile	14	10	7.5	3	8.5	10	5	7	0.16
	50	Median	19	15	10	6	11	15	8	11	0.29
	75	3rd quartile	24	19	15	10	17.5	20	14.5	15	0.47
	90		30	20	18	16	22	25	17	20	0.63
	95		35	25	20	22.5	27.5	28	20	22.5	0.75
		upper whisker	35	28	25	19	28	35	24	25	0.81
N			109	109	109	109	109	109	109	109	109

Table 16: Percentile Table of Input- and Output-Parameter

7.8 Selection of Suitable Multivariate Regression Methods and Optimization Approaches

The next step, after the successful collection of data, is to select the most suitable multivariate regression and optimization approach for the data and its conditions. Optimization consists of two steps, the first being regression of data points on the input side. The second step is the actual optimization. Depending on the nature of the data and the underlying conditions, different regression approaches need to be evaluated for applicability. Eight different regression methods were selected for evaluation. Table 17 outlines the methods, a brief introduction, and the reason for the selection or dismissal of the method.

Regression Method	Description	Applicability for data-set
Least Square	One of the oldest and most used regression methods. It can be used when there is a linear relationship between the dependent and independent variables [97]. Formula: $y=\beta 0+\beta 1*x+\varepsilon$	**Dismissed**. Scatterplot analysis indicates the nonlinear nature of the data.
Partial Least Square	This method uses the same approach as the normal least square method; it does not address the original data, but uncorrelated variables instead. The main advantage of this method lies in the possibility to address multiple output variables if necessary [98].	**Dismissed**. Multiple output variables are not needed.
Polynomial Regression	This method creates a polynomial function with the following structure [99]: $p(x)=p_1x^n+p_2x^{n-1}+\cdots+p_nx+p_{n+1}$	**Dismissed.** Scatterplot analysis indicates nonparametric behavior.
Logistic Regression	This method can be used if a categorical output is available and to make the output categories comparable with each other. This is especially helpful if future predictions are needed about how the input will be assigned to a specific output category [100].	**Dismissed.** The output variable is a single value of the combined sum of project health factors. It is not a categorical output (like yes or no).
Kernel Smoothing	This nonparametric method determines a density function to forecast the probability at which input variables reside in a certain area. The advantage of this method is the capability to identify nonlinear relations between input and output variables [101].	**Dismissed.** The goal of the regression step is to create an actual regression function suitable for optimization. The probability of input variable locations is not in focus.
Stepwise Regression	This method uses an iterative approach where variables can be added or deleted in each iteration [97]. In each iteration, the variable with the highest correlation to the output variable is identified using the p-values of the variables.	**Used.** A second-degree polynomial regression function generates a satisfying result.
Lasso Regression	Lasso stands for least absolute shrinkage and selection operator. This iterative method minimizes variables that are not relevant until they are zero [102].	**Dismissed.** Increased complexity in this regression approach is not necessary as a suitable regression with an acceptable p-value result can be obtained with stepwise regression. However, this method could be applied in different similar use cases.
Ridge Regression	In contrast to Lasso, ridge regression never sets the value of coefficients to absolute zero [103].	**Dismissed.** Not all coefficients are necessary.

Table 17: Regression Method Selection

After evaluating the different regression methods and selecting stepwise regression as the most applicable for the collected data, a nonlinear optimization approach including additional constraints was chosen to identify a suitable maximum of combined project health factors in relation to the best distribution of project process relevance factors.

The MATLAB solver *fmincon* finds the minimum of a problem with these constraints:

$$\min_x f(x) \text{ such that } \begin{cases} c(x) \leq 0 \\ ceq(x) = 0 \\ A \cdot x \leq b \\ Aeq \cdot x = beq \\ lb \leq x \leq ub \end{cases} \tag{1}$$

b and *beq* are vectors, *A* and *Aeq* are matrices, *c(x)* and *ceq(x)* are functions that return vectors, and *f(x)* is a function that returns a scalar. *f(x), c(x),* and *ceq(x)* can be nonlinear functions [104].

For the optimization approach, the following constraints were defined:

- The initial starting point for the iterative optimization method was defined as the average values of project process relevance, ensuring that the result stays close to a common distribution defined by the survey participants.
- The sum of all project process relevancies needed to be 100%.
- Upper and lower bounds of project process relevancies were defined with +/- 10% of the average values. This ensures that the optimization avoids extreme results, for example maximizing one project process to 100% and minimizing all other project process relevancies to 0%.
- No linear inequality constraints were defined.

7.9 Regression including Fine-tuning

After defining, the actual optimization process in MATLAB R2018a [12] was performed including data cleaning. Based on the input data, an initial import to MS Excel was used, converting the textual structure of the raw data into table form suitable for MATLAB import. The result of this import can be seen as an example below in the form of table 18 for the first 8 data sets.

It needs to be noted that the four project health factors were added up to a single output value, divided by 400, and then inverted and the reciprocal value was taken to utilize the minimization solver of MATLAB for the maximization of project health.

P1	P2	P3	P4	P5	P6	P7	P8	Budget	Scope	Schedule	Customer	Output
14	20	18	14	28	1	3	2	19	21	14	23	0.8
19	9	6	4	8	35	7	12	92	100	87	100	0.1
14	20	18	14	28	1	3	2	19	21	14	23	0.8
20	13	17	0	15	13	4	18	53	100	30	100	0.3
45	10	10	10	10	5	5	5	100	80	80	90	0.1
15	5	10	5	20	15	10	20	85	70	70	70	0.3
24	15	12	11	20	11	0	7	88	52	61	77	0.3
5	20	20	5	5	25	5	15	100	60	85	85	0.2

Table 18: Example of 8 Data-Sets after Data Cleaning in MS Excel

After importing the cleaned data into MATLAB, the nonlinear stepwise regression approach of the second order was used to determine a suitable regression function:

>> mdl=stepwiselm(Input,Output,'poly22222222') (2)

Where:

Input = the input matrix of processes 1 to 8

Output = the single-column output matrix

As a result of this regression, MATLAB estimates these coefficients and statistical values for the regression function (MATLAB uses x1 to x8 as variables for parameters instead of P1 to P8) as shown on Figure 9.

```
Linear regression model:
    y ~ [Linear formula with 20 terms in 7 predictors]

Estimated Coefficients:
                    Estimate          SE         tStat       pValue
                   ___________    __________    _______    __________

    (Intercept)         2.7137       0.40185     6.7532    1.4348e-09
    x2                -0.10848      0.022194    -4.8879    4.4806e-06
    x3               -0.048817      0.011527     -4.235    5.5528e-05
    x4               -0.050159      0.012635    -3.9697    0.00014556
    x5                -0.14184      0.025389    -5.5867    2.4917e-07
    x6                0.010794     0.0077276     1.3968       0.16595
    x7               -0.012229     0.0060357    -2.0261      0.045745
    x8                 -0.0523      0.015257    -3.4279    0.00092325
    x2^2             0.0016605    0.00045057     3.6854    0.00039187
    x2:x3            0.0009295    0.00055861      1.664      0.099637
    x2:x4             0.001499    0.00046722     3.2083     0.0018564
    x2:x5            0.0023624    0.00053829     4.3887    3.1259e-05
    x3:x5            0.0024357     0.0005016      4.856    5.0904e-06
    x4:x5            0.0014501    0.00048697     2.9778     0.0037398
    x5^2             0.0013674    0.00040192     3.4023     0.0010031
    x6^2           -0.00059705    0.00022073    -2.7049     0.0081865
    x5:x7            0.0015535    0.00040174      3.867    0.00020926
    x2:x8            0.0013149    0.00061499     2.1381      0.035245
    x4:x8            0.0010384    0.00039165     2.6513     0.0094919
    x5:x8            0.0019123    0.00058222     3.2845      0.001462


Number of observations: 109, Error degrees of freedom: 89
Root Mean Squared Error: 0.15
R-squared: 0.578,  Adjusted R-Squared 0.488
F-statistic vs. constant model: 6.43, p-value = 4.49e-10
```

Figure 9: Stepwise Regression Results

As highlighted in the red boxes in the figure the p-values of the sixth process x6 and the combined factor x2*x3 are too high based on the 5% proposed p-value cut-off [105] with values of 16% and 10%. This indicates that there might be critical collinearity of the sixth process in relation to the output. Therefore, an additional correlation matrix was developed to ensure that all the processes are within acceptable correlation boundaries regarding the correlation.

The correlation matrix in table 19 shows that the absolute value of the Pearson correlation coefficient is with a maximum of 0.32 less than 0.8, so multi-collinearity is less likely to exist [106].

		P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
P2	Correlation	-0.158							
	Significance	.101							
P3	Correlation	0.026	-0.012						
	Significance	0.786	0.905						
P4	Correlation	-0.349**	-0.064	0.006					
	Significance	0.000	0.511	0.950					
P5	Correlation	-0.293**	-0.214*	-0.127	0.204*				
	Significance	0.002	0.026	0.188	0.034				
P6	Correlation	-0.023	-0.305**	-0.248**	-0.376**	-0.195*			
	Significance	0.810	0.001	0.009	0.000	0.042			
P7	Correlation	-0.237*	0.098	-0.221*	-0.152	-0.194*	-0.178		
	Significance	0.013	0.311	0.021	0.114	0.043	0.065		
P8	Correlation	-0.251**	-0.114	-0.287**	-0.225*	-0.194*	0.074	0.113	
	Significance	0.008	0.240	0.002	0.019	0.043	0.444	0.243	
Output	Correlation	-0.040	**0.321****	-0.141	0.076	0.163	-0.323**	0.163	-0.127
	Significance	0.682	0.001	0.143	0.432	0.091	0.001	0.090	0.190
** p < 0.01 (two-tailed)									
* p < 0.05 (two-tailed)									
N=109									

Table 19: Correlation Matrix with all Variables

Keeping the critical process P6 static, the partial correlation matrix in table 20 also indicates no critical collinearity between the other input variables and the output variable.

			P1	**P2**	**P3**	**P4**	**P5**	**P7**	**P8**
P6	**P2**	Correlation	-0.173						
		Significance	0.073						
	P3	Correlation	0.021	-0.095					
		Significance	0.828	0.330					
	P4	Correlation	-0.386**	-0.202*	-0.097				
		Significance	0.000	0.036	0.317				
	P5	Correlation	-0.303**	-0.293**	-0.185	0.144			
		Significance	0.001	0.002	0.056	0.138			
	P7	Correlation	-0.245**	0.047	-0.278**	-0.24*	-0.237*		
		Significance	0.010	0.632	0.004	0.012	0.014		
	P8	Correlation	-0.250**	-0.096	-0.278**	-0.213*	-0.184	0.128	
		Significance	0.009	0.324	0.004	0.027	0.057	0.186	
	Output	Correlation	-0.050	0.247**	-0.242*	-0.052	0.107	0.114	-0.109
		Significance	0.608	0.010	0.012	0.596	0.269	0.242	0.262
** p < 0.01 (two-tailed)									
* p < 0.05 (two-tailed)									

Table 20: Partial Correlation with P6 as Control Variable

It can be concluded that high p-values may not be critical regarding the validity of the regression model. When combining x2 and x3 factors, the significance level is with

0.099 not as critical as the previously proven uncritical P6 process. For further analysis, the model is accepted as the basis for optimization even at this significance level.

7.10 Optimization of Process Relevance Factors

As the next step, the regression function is maximized under certain boundaries and conditions to propose an optimum distribution of project process relevance factors. Using the developed regression coefficients, the following regression function is defined as:

```
fun=@(x)+2.7137-0.10848*x(2)-0.048817*x(3)-0.050159*x(4)-0.14184*x(5)
+0.010794*x(6)-0.012229*x(7)-0.0523*x(8)+0.0016605*x(2)^2
+0.0009295*x(2)*x(3)+0.001499*x(2)*x(4)+0.0023624*x(2)*x(5)
+0.0024357*x(3)*x(5)+0.0014501*x(4)*x(5)+0.0013674*x(5)^2
-0.00059705*x(6)^2+0.0015535*x(5)*x(7)+0.0013149*x(2)*x(8)
+0.0010384*x(4)*x(8)+0.0019123*x(5)*x(8);
```
(3)

As an initial starting point for the optimization, the average project process relevance factors are used:

```
x0=[19.0;14.3;11.1;7.7;12.8;14.8;9.1;11.3]
```
(4)

The constraint affecting all input variables adding up to 100 is defined as such:

```
Aeq=[1 1 1 1 1 1 1 1]
beq=[100]
```
(5)

The constraint delineating the upper and lower bounds of the process relevance factors with +/- 10% of the average value, however, at least 5%, is defined as such:

```
ub=[29.0 24.3 21.1 17.7 22.8 24.8 19.1 21.3]
lb=[ 9.0 5.0 5.0 5.0 5.0 5.0 5.0 5.0]
```
(6)

Linear inequality constraints are defined as such:

```
A=[]
b=[]
```
(7)

The optimization solver x=fmincon(fun,x0,A,b,Aeq,beq,lb,ub) uses a sequential quadratic programming method [107,108] and generates a suitable optimization result.

7.11 Results and Interpretation

As an overall result of the optimization phase, it can be concluded that the best distribution of project process relevance factors for the defined scope and boundaries based on the currently collected data looks as shown in table 21:

Project Process	Optimized Project Process Relevance in %
P1: Direct and Manage Project Work	9.0
P2: Manage Project Knowledge	8.8
P3: Manage Quality	21.1
P4: Develop Team	5.0
P5: Manage Team	5.0
P6: Manage Communications	24.8
P7: Implement Risk Responses	5.0
P8: Manage Stakeholder Engagement	21.3

Table 21: Result of Optimization

It is obvious that defining the upper and lower boundaries as constraints has a large influence on the optimization value. All final values, except the process “Manage Project Knowledge”, are situated either in an upper or lower boundary. This indicates that the optimization step would bring some project processes to zero and continue maximizing other project processes. To get a better understanding of these trends, it is helpful to repeat the optimization without upper and lower boundaries.

Table 22 shows that the optimization without boundaries maximizes only two project processes and sets all other project processes to 0%. This approach suggests putting 78.4% of focus or relevance on the process of “Manage Team” and 21.6% of “Develop Team”. Naturally, these values are far from realistic and usable. Yet, they can visualize the importance of Team Management for the available data set for project success.

Project Process	Optimized Project Process Relevance with Upper and Lower Boundaries in %	Optimized Project Process Relevance without Upper and Lower Boundaries in %
P1: Direct and Manage Project Work	9.0	0
P2: Manage Project Knowledge	8.8	0
P3: Manage Quality	21.1	0
P4: Develop Team	5.0	21.6
P5: Manage Team	5.0	78.4
P6: Manage Communications	24.8	0
P7: Implement Risk Responses	5.0	0
P8: Manage Stakeholder Engagement	1.2	0

Table 22: Result of Optimization Considering Boundaries

The selected boundaries of +/-10% of the average value are open for discussion or change. These boundaries can also be seen as a damper protecting the optimization from being too radical and therefore proposing unrealistic values to project managers.

To interpret the constrained optimization results further, the individual processes are broken down into more details.

P1: Direct and Manage Project Work is the process of implementing and doing the work defined in the project plan [109]. In the boundary restricted result, this process shows relevance of 9.0%, which is situated in the lower boundary. It is worth mentioning that the peer-reviewed paper [110] by Rosenberger and Tick used nearly the same set of data. 103 out of 109 data sets were identical. However, this small increase in available data sets changed the optimization result drastically. In [110] the process "Direct and Manage Project Work" had the highest significance. This situation indicates that much more data needs to be collected to acquire stable results. The current optimization results are still not ready to be taken as advice and input for project managers but only serve as a proof of concept that multivariate optimization can be used to optimize project process relevance distributions.

The optimized relevancies for the processes **P2: Manage Project Knowledge** and **P7: Implement Risk Responses** are both situated in the allowed minimum values. Explaining this behavior is not within the scope of this research. However, it could be suggested that a healthy project needs less of the troubleshooting-oriented project processes, like managing risks and lack of project knowledge. One could argue that a project manager can move towards a positive circle within the project. So, if he or she is not busy implementing risk responses, for example, more time for important processes like communication makes a healthy project even healthier.

The processes of **P3: Manage Quality** and **P6: Manage Communication** show drastic differences in both variances of the optimization approaches. The optimization with boundaries resulted in high project process relevance factors of around 21% and 25%, whereas in the optimization without boundaries, the relevance factors drop to 0%. This behavior could be a result of a realistic situation in which the majority of project managers do the processes quite often to be successful. However, strictly from a mathematical point of view, the optimum looks different. The advantage of optimization conditions and boundaries lies in exactly this behavior. They can be used to adjust strict and maybe unrealistic mathematical outcomes into realistic and lifelike situations.

The processes **P4: Develop Team** and **P5: Manage Team** show similar behavior as the processes "Manage Quality" and "Manage Communication", however with inverted results. The processes are minimized to the lower boundary in the restricted optimization attempt and maximized to 22% and 78% in the unrestricted optimization.

7.12 Conclusions

The goal of this research phase was to show that multivariate optimization methods can be applied for proposing optimized workflow processes to project managers. This approach can reduce the tendency of the project management profession of being subjective, individualistic, and hard to capture. Every project is unique and it is a highly important competence for project managers to be flexible and adapt to the different challenges that occur in their daily work. It has to be noted that this research does not suggest rigorously following the optimized relevance factors. Knowing about an optimized distribution based on data and not on subjective interpretations and recommendations could help to highlight how successful project managers do their work and consequently, act as a guideline for all other project management practitioners. The result of this research phase is a proof of concept, showing the potential of an optimization approach and the challenges involved in using constraints to adapt unrealistic results, if needed. It answers the research questions Q.2.1 and Q.2.2:

(Q.2.1) How can information about success and the way project management practitioners do their work be transformed into data usable for optimization and optimized with mathematical methods?

The use of a custom-developed survey application proved successful in collecting project process relevance factor distributions and project health factors, which are later merged into one single output factor for multivariate optimization.

(Q.2.2) How do optimized project process relevance distributions look depending on defined conditions and boundaries? How can these results be interpreted?

Using stepwise regression proved to be a successful method to optimize the collected data, resulting in project process relevance factor distributions as shown in tables 21 and 22.

Although the optimization approach itself proved to be successful, the actual values and outcomes of the optimization are not yet ready for practical use in project management. Several limitations need to be mentioned to prevent potential misinterpretation. The most important factor is the relatively small set of heterogenic survey participants and the resulting data. For more reliable results to be achieved, additional projects and personal characteristics should be used to filter and preselect data sets for optimization. To create a reliable result, for example, only small, agile developed projects in the financial industry, managed by less-experienced project managers, might be selected. With such a specific selection of categories, many additional aspects and insights could emerge from the data after optimization.

Another limitation that should be mentioned is that many survey participants gave their input during the flow of their projects. There was no phase of introduction about this research from the beginning of their project onwards. Knowing in advance that project process relevance is in focus and measured by a survey application, could lead to less subjective values, increasing the overall quality of the data.

Lastly, a gap in the nature of input and output variables needs to be mentioned. The project health factors are overall values, which are valid for all project phases from the start. Therefore, positive project health could already be transmitted into other project phases. The survey on the input side completely focuses on the execution phase, not considering the results of previous or following phases. This additional influence on the output factors, which overlap with project phases, reduces the significance of the optimization result.

7.13 Thesis 2 based on Hypothesis 2

In the following, Hypothesis 2 is discussed.

(H.2) Optimizing project process relevance factor distributions with suitable multivariate regression and optimization methods is achievable with data collected from project management practitioners. However, the multivariate nature may need a large amount of input data to achieve robust results.

Facilitating the cloud service Heroku [96], a data collection application is developed to record project-specific data of the survey participants. To reduce complexity, only continuous processes of the project execution phase are selected as proof of concept for multivariate optimization. The data showed nonparametric characteristics and the method of stepwise regression as a usable process. The optimization results are presented in tables 21 and 22. However, the result does not seem to be robust, because the optimization results drastically change with only a few additional data-sets.

Hence, Hypothesis 2 is confirmed and can be summarized in Thesis 2.

Thesis 2: Towards Multivariate Optimization of Project Management Frameworks

I analyzed with mathematical-statistical methods project process relevance factor distributions of continuous processes in the project execution phase and project health indicator factors from project management practitioners to serve as a basis for multivariate optimization. The evaluation of various parametric and non-parametric regression methods proved stepwise regression as most applicable. A defined selection of boundaries and conditions for optimization thus creating an optimization result suitable to serve as proof of concept that multivariate optimization is applicable as a novel approach to optimize the project process relevance factor distributions.

Publications supporting Thesis 2: [110,111]

8 Development of a Generic Tailoring and Optimization Model for Process-based Management Frameworks

In this third and last research phase, the steps of optimization are converted into a generic process model that can be applied in many other process-based management frameworks. These development steps are later applied to 6 practical applications.

Firstly, a better understanding of the term “process-based management frameworks” has to be created.

8.1 Process-based Management Frameworks

Process-based management approaches are widely used in different industries and fields other than project management - from knowledge management [112], and quality management [113] to production improvement [114]. All these approaches are based on individual and repeatable steps to improve outcomes. Nevertheless, many of these processes rely on an inductive empirical approach. Often, they contain some part of the PDCA approach, however, this optimization does not affect the process management approach itself. The stated model is static, based on the assumption of maximum effectiveness and applicability. The newly developed generic optimization model follows the steps described in Thesis 2 and therefore pursues the goal of improving and optimizing process-based approaches during their specific application in the sense of a cybernetic system [115].

8.2 Description of Abstracted Process Steps for Model Generation

Based on the clarification of process-based frameworks, a generic optimization model is developed, which is based on steps defined in Thesis 2 and additional steps to increase the applicability and effectiveness of the generic model. The individual steps are briefly described and later modeled utilizing the flow chart methodology.

8.2.1 Scope Selection

The first process step taken to achieve the results of Thesis 2 was the definition of processes that are in scope for optimization and the outcome to be optimized. These activities can be summarized as “Scope Selection”. Often process-based management systems like knowledge management or quality management consist of many activities clustered in different phases that follow each other sequentially. The basic approach of distributing relevance factors relies on the fact that different tasks are performed in parallel and practitioners need to choose what to do. They need to scarify focus on potentially less critical activities to prioritize highly critical activities. Supporting these decisions is the goal of the multivariate optimization approach. To define competitive activities, the process model needs to be analyzed and process steps or activities of relevance have to be defined. As an example, in Thesis 2 continuous processes of the PMBOK execution phase were selected as the scope for the optimization. These tasks need to be performed simultaneously by a project manager. In contrast to this, strictly sequentially performed processes like “Create a project charter” and “Close a project”, are never performed simultaneously. Therefore, developing an optimized distribution of relevance factors would make no sense there.

8.2.2 Data Gathering

The next step of Thesis 2 was the activity of “data gathering” executed by an online survey in a specially developed web portal. It may be sufficient for the purpose to develop a proof of concept for this approach. However, the subjective nature of the participants needs to be mentioned as a major limitation. To overcome this limitation, a split of this process into three subprocess steps is proposed:

- Step 1: Search and evaluate the potential for automated data gathering
- Step 2: Implement automated data gathering where possible
- Step 3: Implement manual and therefore more subjective and error-prone data gathering.

As an additional advantage of a highly automated data collection, the number of data sets should be mentioned. If every little activity of a survey participant is captured automatically, the amount and quality of data will increase much faster compared to having the survey participants think about their tasks and remember what they did and how much time they spent on doing certain tasks.

8.2.3 Data Cleaning

As a next step, the collected data needs to be cleaned and prepared for regression and optimization. This step is common in all big data-related approaches and is well described in various scientific literature [116].

8.2.4 Scatter Plot Analysis

A basic scatter plot analysis may give a valuable indication of which regression method may be most successful. Scatter plots that indicate linear characteristics may indicate the applicability of simple least square regression. Nonlinear characteristics might indicate that non-parametric regression methods like stepwise regression should be used. Nevertheless, it has to be mentioned that more than 3 dimensions reduce the validity of the scatterplot analysis since individual input parameters do not affect the output parameter directly anymore. However, additional insights can be discovered, i.e., realizing that process relevance values are likely to be set as a multiple of 5 or 10 by survey participants.

Figure 10 and 11 show two examples of scatter plots indicating parametric [117] and nonparametric [118] nature of the data:

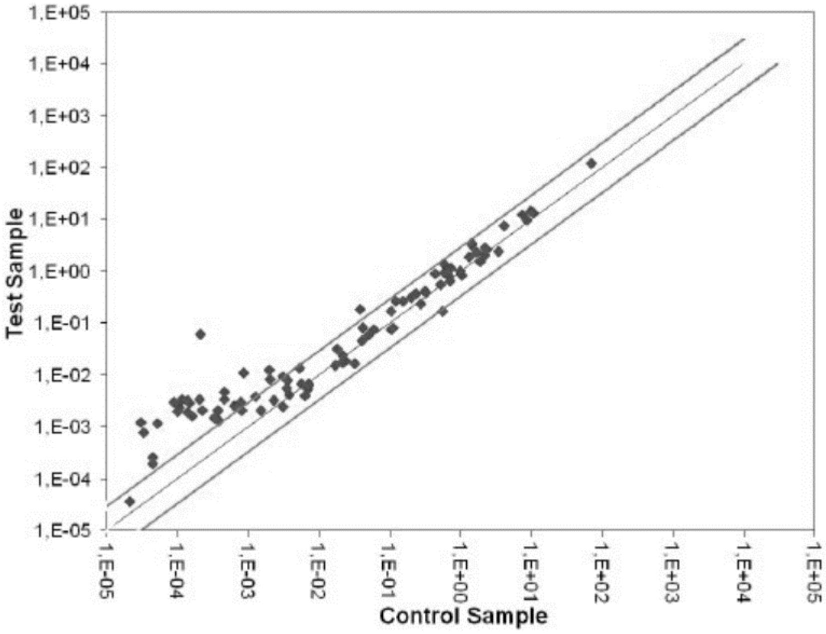

Figure 10: Parametric Characteristics

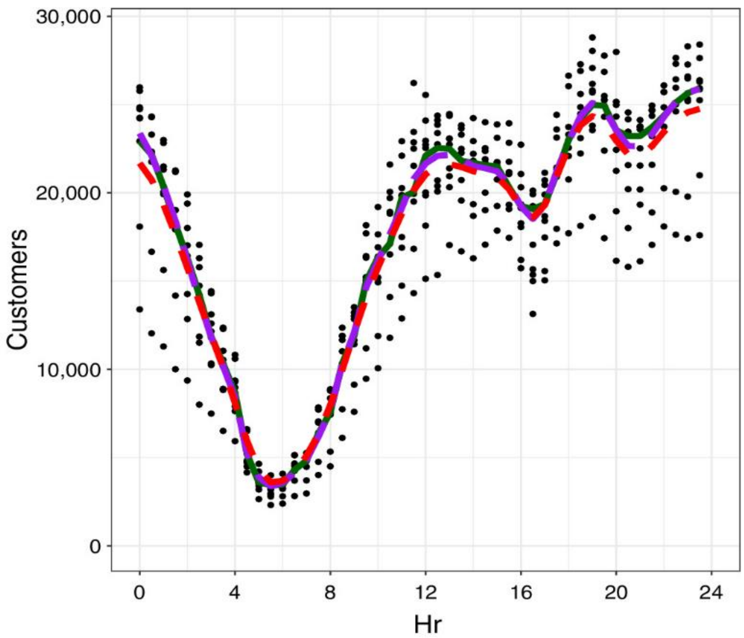

Figure 11: Nonparametric Characteristics

8.2.5 Basic Statistical Analysis

As the next process step, a crosscheck of the most basic statistical values for input and output factors is proposed. This step provides valuable insight into the quality of collected data and provides references for subsequently needed optimization conditions such as starting points of optimization being set at the average values of the input parameters. Traditional box-plot graphics with these values are proposed as suitable:

- Upper whisker
- 3rd quartile
- Median
- 1st quartile
- Lower whisker

8.2.6 Regression and Interpretation of Results

With clean data and initial statistical and graphical evaluation, a regression method can be chosen, applied, and interpreted based on statistical quality indicators like p-values or R-Squared values. In Thesis 2, stepwise regression was identified as the most useful approach for the existing data. However, also simple linear methods like least square can be suitable in other applications.

8.2.7 Definition of Conditions and Boundaries

Every optimization requires the definition of boundaries and conditions. The algorithm of stepwise regression requires starting points, lower and upper bounds, linear equality, and inequality constraints.

This process step provides a great possibility for influencing the outcome and adjusting it to reality. If, for example, some process steps are mandatory and others not, the lower boundaries can be defined accordingly. In Thesis 2, the boundaries have been set to +/-10% of the average value of process relevance factors. This provides a basis for highly implementable results.

With the flexibility of conditions and boundaries in mind, it is obvious that there is no single truth or single outcome for optimization. The optimization approach can only apply data-based answers to questions asked in specific circumstances.

8.2.8 Optimization

After a successful definition of conditions and boundaries, the actual optimization can be performed resulting in a proposed optimized distribution of process relevance factors. These results shall be put into practice after an initial interpretation and discussion and shall affect and adapt the way the process-based management model is executed.

8.2.9 Continuous Monitoring of Improvement

When put into practice, the optimized relevance factors should improve the overall success after some time. Therefore, the last process step is to continuously collect data and monitor the improvement.

8.3 Development of a Generic Optimization Model

Based on the phase descriptions and their allocated tasks of the previous chapter, the following generic process model can be abstracted as shown in figure 12.

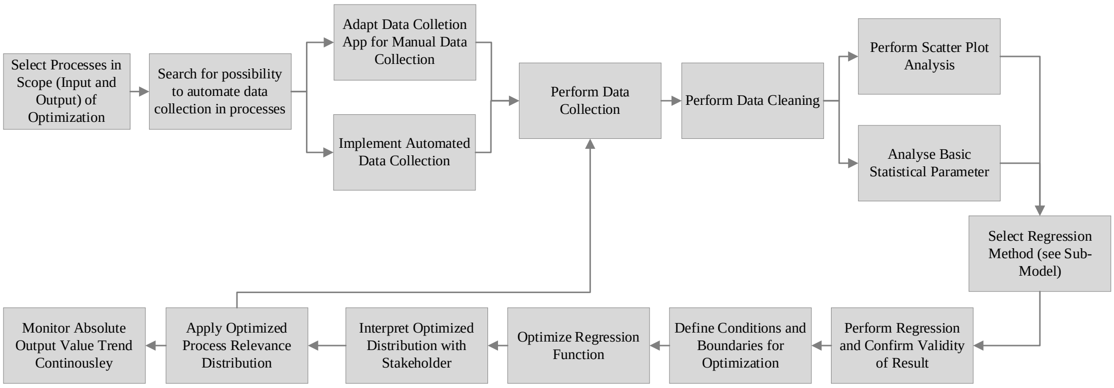

Figure 12: Generic Optimization Model

8.4 Interpretation of Optimization Model

The described optimization model consists of 15 individual steps and tasks. Most of these tasks are simplified short descriptions of the steps taken in Thesis 2. Nonetheless, special attention is needed for the abstracted processes of “Data Collection”. In the first research phase, data collection was performed by using an online survey tool, which simply collected possibly subjective evaluations of survey participants. This lack of objectivity is also mentioned as a limitation of the research. Based on this critical statement, the generic process model implements an automated data collection step. This automation can be seen as another novelty of the model. Besides merely asking practitioners what and how much effort and focus they put into certain tasks, the generic model proposes to implement automated inputs for data collection, which improves the subjective nature of manual survey participation. As an example of such an automated collection, a traditional Sprint iteration in Scrum-based development [22] is portrayed. During each sprint, survey participants may lock in their operating systems to attend Daily Scrum standup meetings and block these times in their individual Outlook calendars. Such information embedded in Software like Outlook or Logfiles of operating systems could be used as a source of automated data collection, adding parameters to a specific process step like “Scrum Meeting Attendance” for example. Also, the time used by a product owner describing and maintaining user stories in modern backlog systems like Jira [119] could be facilitated as an objective and automated data source.

Another aspect of the model that is worth mentioning is the feedback loop from “Apply Optimized Process Relevance Distribution”, back to “Perform Data Collection”. This process step is not yet a part of the optimization described in Thesis 2. It enables the model to be seen as ongoing and dynamic. It can be assumed that using the model will lead to process improvement, resulting in improved and new data-set elements, which can and should be used in future optimization attempts with the model. This simple element of feedback ensures that optimization is not a tool to be used once, but repeatedly and continuously.

8.5 Application of Generic Model on filtered Data-Sets

8.5.1 Introduction to Selected Data-Sets and Sampling

The data set used as a basis for six additional optimization approaches is the same set as applied in Thesis 2. According to the description in Thesis 2, the survey also captured demographic data of the survey participants, and additional information was collected about project-specific characteristics. This additional information is now used to split the data into different categories:

- *Team Together*: This set of filtered data points contains projects in which the team sits physically together in an office or at least in one city.
- *Team Distributed*: This set of data point group projects in which the participants are distributed within one country or internationally
- *Short Projects*: These data points contain projects with a project duration of up to 6 months.
- *Long Projects*: Projects longer than 6 months are grouped in the Long Projects data-set.
- *Good Self Evaluation*: The online survey also requested a self-evaluation about project management proficiency, grading from 1 to 5, and how “self-confident” the participants feel in the practice of project management. The marks 5 and 4 are defined as “good” self-evaluation.
- *Bad Self Evaluation*: The marks of 3 and down towards 1 are defined as “bad” self-evaluation.

Although many other demographic and project-characteristic-related categories have been collected, only these 6 categories are used for the case-study application of the generic process because the amount of data points in these categories is quite high. The lack of available data points is an issue when using multivariate regression and optimization. This issue will also result in critical statistical parameters of the case study application. So, the actual results of the optimization shall not be used due to this limitation. Yet, they serve as a proof of concept that the generic process can also be applied to different sets of data.

This described selection of data sets already covers the first process step of the optimization model approach defining the scope and the processes. The following four process steps of data collection have not been performed as the already collected data has been reused. The step of data cleaning is limited to category-related filtering of already pre-cleaned data tables, including the calculation of basic statistical values like standard deviation and average values for all input and output variables. Scatterplot analysis in two-dimensional diagrams included different plots with a specific input variable in relation to the output variable. Figure 13 presents the scatterplot of process

2 and the output variable of short projects serves as an example. As highlighted with a gray box, a noticeable concentration of input values on the x-axis as a multiple of 5 can be detected. The distribution of the output variable on the y-axis does not seem to concentrate on certain values.

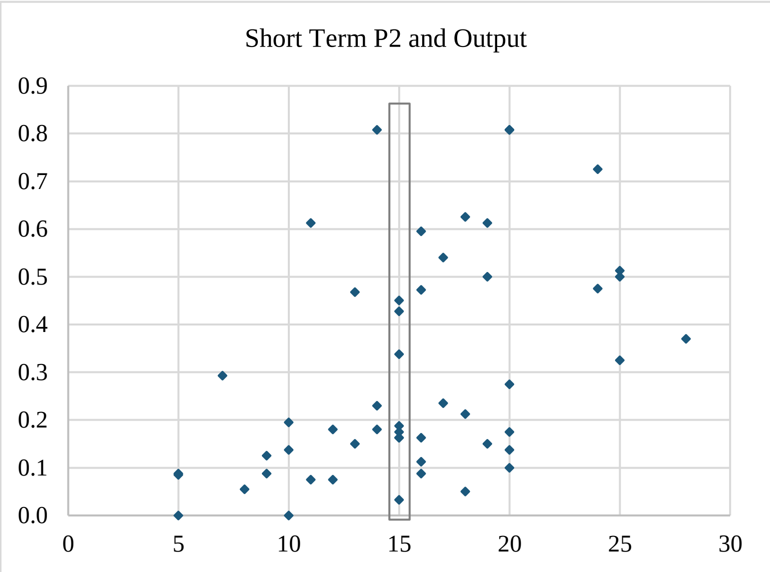

Figure 13: Scatterplot Example

The step of basic statistical analysis was performed without any special insights worth portraying. In the next step of selecting the most suitable regression method, stepwise regression was again selected for all data-set groups as the favorable regression model, even for the reduced amount of data.

After performing and interpreting the regression analysis, the following results were developed:

- Short-term project regression function:
  - 2nd-degree polynomial function with 20 terms in 7 predictors
  - Unsatisfying p-values in the processes x6, x7, x8
  - Root Mean Squared Error: 0.125
  - R-squared: 0.825, Adjusted R-Squared 0.724
- Long-term project regression function:
  - 2nd-degree polynomial function with 7 terms in 7 predictors
  - Unsatisfying p-values in the process x6
  - Root Mean Squared Error: 0.127
  - R-squared: 0.612, Adjusted R-Squared 0.503
- Team Together project regression function:
  - 2nd-degree polynomial function with 13 terms in 7 predictors
  - Unsatisfying p-values in the processes x3, x6^2, x3*x8
  - Root Mean Squared Error: 0.143
  - R-squared: 0.735, Adjusted R-Squared 0.592
- Team Distributed project regression function:
  - 2nd-degree polynomial function with 13 terms in 7 predictors
  - Unsatisfying p-values in the processes x2, x3
  - Root Mean Squared Error: 0.0918

- R-squared: 0.859, Adjusted R-Squared 0.781
- Good Self Evaluation project regression function:
    - 2nd-degree polynomial function with 22 terms in 7 predictors
    - Unsatisfying p-values in the process x3 with a value of 0.169
    - Root Mean Squared Error: 0.14
    - R-squared: 0.707, Adjusted R-Squared 0.573
- Bad Self Evaluation project regression function:
    - 2nd-degree polynomial function with 13 terms in 7 predictors
    - Unsatisfying p-values with the highest in factor x2*x5 with 0.02
    - Root Mean Squared Error: 0.0814
    - R-squared: 0.917, Adjusted R-Squared 0.843

The evaluation revealed that the regression results are not satisfying, mostly due to the lack of a sufficient amount of data. Consequently, in an actual optimization scenario, the data collection process steps must be continued to build a larger data set before proceeding with the subsequent steps. However, to illustrate the concept, the process is continued with the unsatisfying regression results to the next steps of optimization.

The definition of conditions and boundaries is reused from Thesis 2, resulting in a final optimization model as shown in table 23 and figure 14:

% of Process Relevance							
	All Data unfiltered	Team Together	Team Distributed	Short Projects	Long Projects	Good Self Evaluation	Bad Self Evaluation
P1 = Direct and Manage Project Work	9.0	9.4	8.6	14.2	10.6	9.0	29.0
P2 = Manage Project Knowledge	14.0	5.6	19.4	5.6	3.1	4.0	21.6
P3 = Manage Quality	21.1	21.1	1.1	1.4	0.0	20.4	22.2
P4 = Develop Team	0.0	18.4	0.0	17.3	18.0	0.0	0.0
P5 = Manage Team	2.8	4.3	21.3	16.3	22.4	4.0	20.9
P6 = Manage Communications	24.8	21.7	26.5	24.0	25.5	22.3	5.2
P7 = Implement Risk Responses	7.0	0.0	0.0	19.0	0.0	19.0	0.0
P8 = Manage Stakeholder Engagement	21.3	19.5	23.1	2.2	19.6	21.3	1.1

Table 23: Case Study Process Relevance

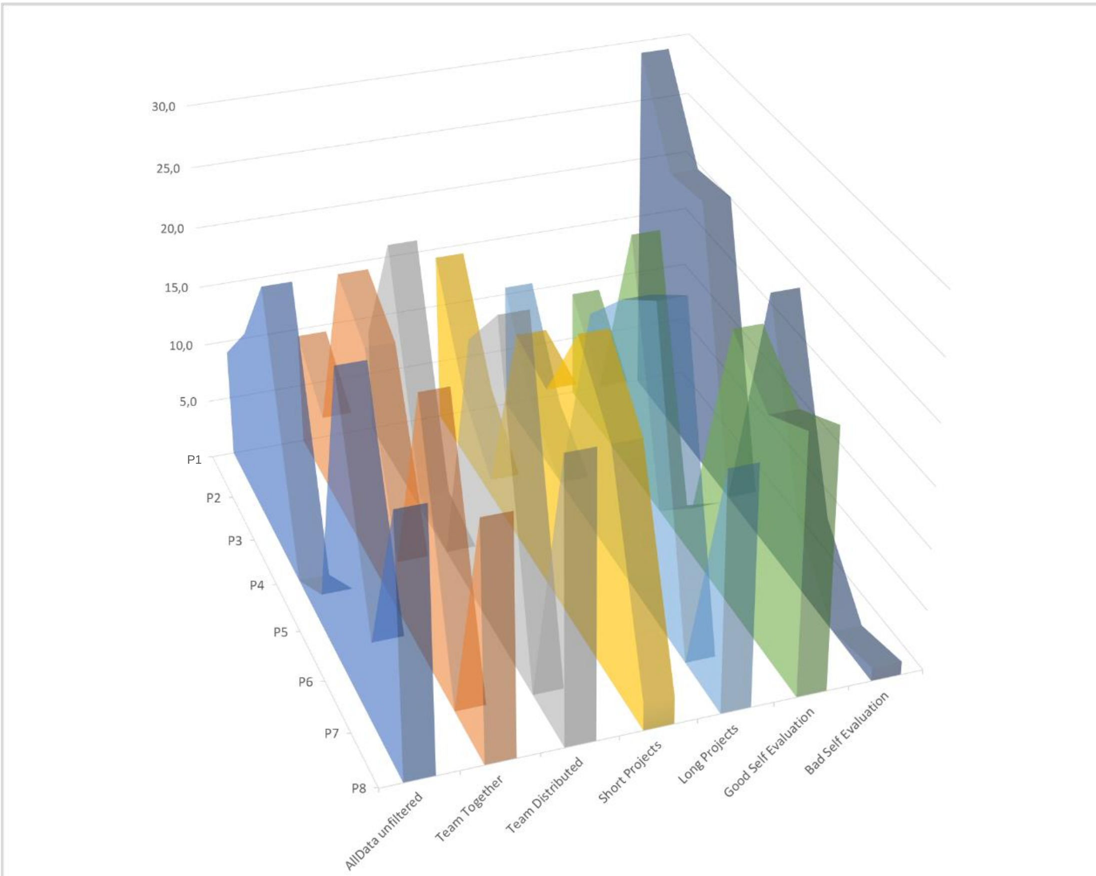

Figure 14: Optimized Case Study Process Relevance Distributions

The process step of interpretation is described in the chapter below. The process steps for application and monitoring of improvements are not covered by this proof of concept optimization attempt.

8.6 Interpretation and Discussion of Results

The goal of this research was the development of a generic process model to optimize process relevance distributions of process-based management frameworks and to verify the applicability of such a model. The application has been successfully performed with 6 different filtered data sets for different project categories. In conclusion, it can be stated that the proposed model can be regarded as applicable. Looking at the results of the actual application and comparing the developed optimization results reveals interesting insights.

To a certain degree, the distributions look related with similar factors of high relevance in the processes of Managing Communication (P6), Manage Stakeholder Engagement (P8), and low relevance in Direct and Manage Project Work (P1). Strangely, there seems to be one outlier. Project managers with bad self-evaluation generated a completely different optimization result. In this group, the best project health is supposed to be created when focusing on Directing and Managing Project Work (P1). Processes tending to be of high relevance in other groups like Manage Stakeholder Engagement and Manage Communications show low relevance in this group. This fact could indicate that inexperienced project managers need to address their projects differently than experienced project managers. Interpreting the other project groups as similar in the way the distributions present themselves, it can be concluded that the way projects need to be managed might not differ too much in different kinds of projects and that project management experience is one key factor distinguishing the best way to address project management.

These interpretations and conclusions must be considered under the circumstances of unsatisfying p-values during regression. This reduces the reliability and meaningfulness of the results. However, interpreting the applicability of the generic process model leads to the conclusion that all undertaken process steps have been quite easy to perform for all 6 different optimization attempts.

In summary, it can be concluded that as the first proof of concept the generic model of process-based management framework optimization is usable if the requirements of all individual process steps are respected and fulfilled.

8.7 Thesis 3 based on Hypothesis 3

In the following, Hypothesis 3 is discussed.

(H.3) As the PMBOK project management framework is merely one kind of process-oriented management framework, the multivariate optimization approach can be abstracted to a novel process model usable in various fields and applications.

Figure 12 presents the abstracted model of a generic optimization model for process-oriented management frameworks. The model is based on steps taken in Thesis 2 and enriched with additional steps like ongoing optimization through feedback loops and automated collection attempts to improve applicability and effectiveness. Figure 14 displays the outcome of optimizing 6 categorical subsets of the collected data using the optimization model. However, Hypothesis H.3 can only be partly confirmed, since newly-integrated process steps of the generic optimization model have not been applied due to restrictions on using subsets of the already collected data. Further, the statistical values of the 6 additional optimizations are unsatisfactory, most likely caused by the low amount of data sets.

As Hypothesis 3 is partly confirmed, Thesis 3 can be summarized as follows.

Thesis 3: Development of a Generic Optimization Model

Based on the optimization approach of Hypothesis 2 and enriched with improvement measures, I created a generic model to optimize all variants of process-based management frameworks. I applied this abstract model to different subsets of process relevance factor distributions to prove its applicability under the restrictions of low numbers of categorical data and some steps not being performed. This novel generic optimization model supports not only the profession of project management but also provides a practicable and usable approach for different industries and management applications to continuously improve the success and quality of their specific outcomes.

A publication supporting Thesis 3: [120]

9 Theses and Contributions

9.1 Theses

Three parts of hypotheses were researched resulting in two complete and one partly confirmed theses.

Thesis 1: Compatibility of Agile Frameworks and PMBOK Project Processes

I conducted a comparative analysis on PMBOK and SCRUM methodologies, based on which I developed a comparison table detailing PMBOK project processes, putting them in contrast to Scrum methods and approaches and identifying 6 critical processes and one potentially critical process regarding compatibility. I supported this problem statement of incompatibility with the creation of an initial project relevance factor matrix, highlighting processes of high criticality in the project management practice. I falsified the criticality of the potentially critical process and proposed applicable and effective solutions for all other critical processes. These combined results improve and tailor the PMBOK version 6 framework for handling agile methods.

Deep literature research was applied to identify and collect scientific publications highlighting critical areas of project management and serving as a basis for the assignment of initial project process relevance factors to PMBOK project processes in 6 different agile and traditional project categories.

The solutions proposed for identified incompatible processes were investigated for applicability and effectiveness using a large-scale quantitative survey and detailed statistical analysis.

Thesis 2: Towards Multivariate Optimization of Project Management Frameworks

I analyzed with mathematical-statistical methods project process relevance factor distributions of continuous processes in the project execution phase and project health indicator factors from project management practitioners to serve as a basis for multivariate optimization. The evaluation of various parametric and non-parametric regression methods proved stepwise regression as most applicable. A defined selection of boundaries and conditions for optimization thus creating an optimization result suitable to serve as proof of concept that multivariate optimization is applicable as a novel approach to optimize the project process relevance factor distributions.

Facilitating the cloud service Heroku [96], I developed a data collection application to collect demographic and project-specific data of survey participants. To reduce the complexity caused by too many input variables for optimization, only continuous processes of the project execution phase were selected for the proof of concept of multivariate optimization.

Eight different optimization approaches were evaluated based on different regression methods. These cover parametric and non-parametric approaches. Stepwise regression was selected as the most applicable regression method and boundaries and conditions for the optimization step were defined to create a result that is realistic for everyday use.

The optimization results of the constrained and unconstrained optimization are shown and the results, which act as a proof of concept of the applicability of the optimization attempt, were compared and interpreted. These results are supported by additional statistical validation of the data set.

Thesis 3: Development of a generic optimization model

Based on the optimization approach of Hypothesis 2 and enriched with improvement measures, I created a generic model to optimize all variants of process-based management frameworks. I applied this abstract model to different subsets of process relevance factor distributions to prove its applicability under the restrictions of low numbers of categorical data and some steps not being performed. This novel generic optimization model supports not only the profession of project management but also provides a practicable and usable approach for different industries and management applications to continuously improve the success and quality of their specific outcomes.

Abstracted process steps were described to perform a multivariate regression and optimization approach generically based on the steps taken in Hypothesis 2. These were enriched with additional steps like ongoing optimization through feedback loops and automated data collection attempts.

Six different subsets of data serve as the basis for case study applications for the optimization model resulting in 6 different distribution results. Although the process itself can be followed during this application, this part of the Hypothesis can only be partly confirmed since proposed process steps, like automated data collection, are not included in the case study and some of the optimization results show unsatisfying statistical parameters, resulting in low trustworthiness of the actual optimization values.

9.2 Contributions

Below, the contributions to the 3 different theses described in the preceding chapters are collected, followed by a list of publications that resulted during this research project.

9.2.1 Related Work and Novelty

Thesis 1

I reviewed literature in the field of the PMI project management framework PMBOK and the agile development framework Scrum.

The compatibility of both approaches was compared and critical project processes of PMBOK version 6 were highlighted when confronted with agile development approaches. This resulted in the presentation of 6 specific challenging processes, which were described in detail.

Literature was reviewed for solutions to close the identified gaps. An online survey was developed to prove the effectiveness of the proposed solutions with statistical analysis to tailor the PMBOK project management framework to agile needs. Furthermore, I falsified the potential criticality of the project closeout process with an online survey and statistical analysis.

Based on scientific literature research, publications were collected highlighting critical processes in project management. They were assigned to project categories to form a table of initial project process relevance factors.

Own publications related to this research phase summarized in Thesis 1 are: [53,85,88,87,86]

Thesis 2:

I defined a multivariate optimization goal and developed a data collection application to collect needed data for the optimization as well as demographic and project-categorical data of the survey participants.

Different parametric and non-parametric optimization methods were evaluated, which was followed by a selection of the most suitable ones.

Boundaries and conditions for the optimization were defined to facilitate realistic results and their interpretation. The optimization results and conditions were supported with additional statistical analysis.

Own publications related to this research phase summarized in Thesis 2 are: [110,111]

Thesis 3:

I described abstracted process steps to perform a multivariate regression and an optimization model usable for different process-based management frameworks based on the approach successfully used in Thesis 2.

The approach of Thesis 2 was enriched and improved with additional steps like a feedback loop for continuous improvement and automated data collection.

The generic model was applied to 6 different subsets of the collected data set resulting in 6 unique optimization results.

An own publication related to this research phase summarized in Thesis 3 is: [120]

9.2.2 List of Own Publications

The list below contains all the publications related to this research project, sorted by time and starting with the most recent publication:

- P. Rosenberger and A. Tick: “A Generic Approach for Multivariate Process Optimization” in the conference proceedings of IEEE 20th Jubilee World Symposium on Applied Machine Intelligence and Informatics (SAMI 2022) in Slovakia, March 2022
    - Introducing the generic regression and optimization model
    - Proving applicability with 2 case study applications of the model on 2 data-subsets
- P. Rosenberger and J. Tick: “Multivariate Optimization of PMBOK, Version 6 Project Process Relevance” in Acta Polytechnica Hungarica, 18 (11), December 2021 [110]
    - Defining the optimization goal
    - Introducing the developed data collection application
    - Selecting a non-parametric optimization method
    - Interpreting the optimization results.
- P. Rosenberger and J. Tick: “Agile Enhancement of Critical PMBOK Project Processes” in the Journal of Modern Project Management, Issue 9 (1). August 2021 [86]
    - Proposing solutions for 5 critical PMBOK project processes
    - Describing a quantitative online survey to explore the applicability and current state of use of the proposed solutions
    - Analyzing the survey statistically.
- P. Rosenberger and J. Tick: “Applicability of Traditional Project Closeout Approaches in Agile Developed IT Projects”, published by Springer in the proceedings book of the 4th International Conference on Design, Simulation, and Manufacturing: The Innovation Exchange (DSMIE-2021), Ukraine, June 2021 [88]
    - Falsifying the Hypothesis of the criticality of the project process of project closing.
- P. Rosenberger and J. Tick: “Applicability of Multivariant Linear Optimization for Project Process Relevance Modeling” in the conference proceedings of Sixth International Scientific Conference on Project Management in the Baltic Countries, Latvia, April 2020 [111]
    - Dismissing unconstrained parametric least square regression as suitable for the optimization approach.
- P. Rosenberger and J. Tick: “Relevance of PMBOK v6 Processes for Tailored Agile Project Categories” in the conference proceedings of IEEE 13th International Symposium on Applied Computational Intelligence and Informatics (SACI 2019) in Romania, May 2019 [87]
    - Developing initial relevance factors based on a literature review for 6 selected project categories.
- P. Rosenberger and J. Tick: “Adaptation of selected PMBOK processes to fit Scrum developments” in the conference proceedings of the Fifth International Scientific Conference on Project Management in the Baltic Countries, Latvia, April 2019 [85]
    - Proposing Solutions for critical PMBOK processes.

- P. Rosenberger and J. Tick: "Suitability of PMBOK 6th edition for agile developed IT Projects" in the conference proceedings of 18th IEEE International Symposium on Computational Intelligence and Informatics (CINTI 2018), Budapest, November 2018 [53]
    - Comparing PMBOK version 6 project processes with the Scrum agile development framework
    - Identifying 5 critical process areas regarding compatibility.

10 Perspectives and Conclusion

Below a conclusion is provided and new approaches are described to evolve the results developed in this research and relativize persistent limitations.

10.1 Perspectives

Thesis 1 evaluates the compatibility of PMBOK version 6 processes and the Scrum development framework. The analysis is based on assessing the tasks of both, the PMBOK processes and Scrum development. At present, the selection of critical project processes is scientifically relatively undiscussed and unproven. A broad quantitative survey over different industries, questioning the identified critical processes would strengthen the research problem statement of agile incompatibilities.

The tailoring applied to critical processes in the form of specific solutions could also be enriched with additional and alternative solution approaches. Based on such a broad pool of possible solution methods, research efforts to select the best solution approaches relying on a case-study-based comparison could improve the tailored project management framework even more.

In addition to improving the selected PMBOK framework, other project management frameworks like PRINCE2 and IPMA should also be investigated regarding their compatibility with Scrum. However, due to the different basic setups of these frameworks, a different approach might be required. PRINCE2, for example, does not suggest how to do tasks, but only what to do [3].

Thesis 2 acts as a proof of concept for multivariate optimization to be applicable for project process relevance distribution optimization. This concept of optimizing such distributions needs to be addressed in various scenarios to improve the practice of project management. The optimization process could be applied with a larger set of data, in different project phases and process-based management frameworks other than project management. Not only would such a broad use and application generate valuable insight about an improved way of doing these processes, but it could also further improve the optimization approach as such as well. New insights could be gained by varying the boundaries and conditions of the optimization process steps and measuring the rate of improvement. Researching alternative methods to define starting points for optimization could specifically create more realistic and relevant optimization results. Various methods are described in scientific literature, which are worth trying within this field of application [121,122].

Another possible approach to improve the validity and quality of the optimization result is the integration of as much automated data as possible into the data collection phase.

So far, the optimization approach is based on subjective process relevance estimations of project management practitioners. Using hard-fact data like measured duration of different kinds of project meetings, for example, could tackle this limitation and improve the reliability of the outcome.

One limitation of Thesis 3 is the fact that the case studies evaluating the generic optimization model are based on the same data set and scope as the optimization approach of Thesis 2. To increase the reliability of the generic optimization model, two directions of improvement could be applied. On the one hand, all process steps of the model should be included in the verification. This is not the case in Thesis 3, as the feedback loop enabling continuous improvement has not been tested yet. On the other hand, completely different optimization scopes should be applied. A proper start could be optimizing the process relevance factor distributions of tasks within a specific Scrum sprint.

All three theses of this research together provide a proof of concept that the practice of agile project management benefits from tailored solutions and the usage of multivariate optimization. Finding the best and most efficient way of practicing the proof of concept approaches is the next logical step from a research project point of view.

10.2 Conclusion

In this Doctoral Thesis, I presented three major parts of developing optimized tailoring of agile project management frameworks in form of three theses building on each other.

Based on an initial introduction of PMBOK version 6 and Scrum, a comparison table was developed which highlights these 6 project processes with critical compatibility and one process with potential critical compatibility:

Critical processes:

- Manage Execution
- Develop Project Structure Plan
- Develop Project Schedule
- Estimate and Define Costs based on Requirements
- Manage Team
- Develop Team

Potentially critical process:

- Closing Project or Phase

Based on this initial result, also acting as a problem statement, I falsified the assumption of the criticality of project closeouts and defined these solutions:

- Strike system for the process “Manage Project Execution“
- Adapted strike system for the processes “Develop Team” and “Manage Team“
- Macro- and micro-planning for the process “Develop Project Structure Plan“
- Macro- and micro-planning for the process “Develop Project Schedule“
- Hybrid approach MVP and velocity planning for the process "Estimate and Define Costs based on Requirements”

A large-scale online survey proves the solutions to be applicable and useful for project management practitioners.

Based on substantial literature research, publications were collected highlighting critical areas of project management. They were assigned to PMBOK project processes in 6 different project categories forming a table of initial project process relevance factors. This result as such provides an additional possibility for project management practitioners to evaluate process relevance factors for different project categories.

The described results together form Thesis 1 of the research project, providing a tailored project management framework to be applied for agile developed IT projects.

After improving the project management practice of “what to do” when managing agilely developed projects, I developed an approach to indicate “how much” to execute project management processes to increase project health and success. To serve as proof of concept, I chose a data-driven approach collecting data from practitioners with a self-developed cloud-based survey application. For data collection, continuous processes of the project execution phase were chosen. The defined processes formed the input parameter of the optimization approach and a summarized project health indicator as the output parameter being optimized.

Different optimization approaches were evaluated based on parametric and nonparametric regression methods. Stepwise regression was selected as the most applicable regression method and boundaries were defined to create a realistic optimization result.

Chosen constraints and boundaries proved to have a large influence on the optimization result, which necessitated a comparison of restrained and unrestrained optimization. These results were supported by additional statistical validation of the data set.

This proof of concept for a successful multivariate optimization formed Thesis 2 of this research project.

Lastly, and summarized in Thesis 3, I abstracted the process steps of Thesis 2 into a generic optimization model and enriched these steps with additional steps like ongoing optimization through feedback loops and automated data collection attempts to be applicable for all possible process-based management frameworks.

Six different subsets of data serve as input for case study applications for the optimization model resulting in six different distribution results. Although the generic model itself could be followed during this application, Hypothesis 3 could only be partly confirmed as proposed process steps, like automated data collection, have not been included in the case study and some of the optimization results show unsatisfying statistical parameters, resulting in low trustworthiness of the actual optimization values.

It can be concluded that this overall research project and its results not only improve the compatibility between traditional project management according to PMBOK version 6 and agile development but also applies a novel approach to facilitating multivariate regression and constrained optimization. Thereby practitioners are provided with more than project management, i.e., a process-oriented management framework with a model to improve the way of doing management tasks in everyday work.

11 Appendix – Raw Data for Optimization and Surveys

The raw data for optimization and different surveys can be accessed via this link:

https://www.researchgate.net/publication/360362450_Raw_Data_Collection

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