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# Project Portfolio Decision Support Using Evolutionary Algorithms

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## **Danksagung**

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Besonderen Dank gilt meinem Vater, Ernst Kremmel, für seine langjährige Unterstützung. Für die Betreuung meiner Arbeit möchte ich hiermit Ao. Univ. Prof. Dr. Stefan Biffl herzlichst danken. Mit wertvollen Ideen und Ansätzen zur Lösung von Schwierigkeiten stand er ständig zu meiner Verfügung. Darüber hinaus möchte ich auch Prof. Dr. Jiri Kubalik, dem Erfinder des benutzten Optimierungs-Algorithmus, vielen Dank aussprechen. Unter großem zeitlichen Einsatz war er immer zur Unterstützung meiner Arbeit bereit und stand mir immer mit fachlichem Rat zur Seite.

Diese Arbeit ist meinen Eltern, Herlinde und Ernst Kremmel, gewidmet.

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## **Eidesstaatliche Erklärung**

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Ich erkläre an Eides statt, dass ich die vorliegende Arbeit selbstständig und ohne fremde Hilfe verfasst, andere als die angegebenen Quellen nicht benützt und die den benutzen Quellen wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe.

Thomas Kremmel, 0200905

**Abstrakt.** Mehrzieloptimierung, Gruppen-Entscheidungs-Unterstützung und Visualisierung von komplexen Daten sind die Hauptforschungsthemen dieser Arbeit. Jener Teil der Arbeit der sich mit Mehrzieloptimierung beschäftigt, zeigt wie das Projekt-Auswahl-Problem im Portfolio Management gelöst werden kann. Der Bereich der Gruppen-Entscheidungs-Unterstützung und Visualisierung von komplexen Daten wird durch die Erstellung eines Portfolio-Auswahl-Prozesses behandelt. Studenten und wissenschaftlich an den Bereichen evolutionäre Optimierung, Projekt Portfolio Management und Gruppen-Entscheidungs-Unterstützung, interessierte Personen sind die Hauptadressaten der vorliegenden Arbeit. Entscheidungsträger, die im Portfolio Management tätig sind, können in der vorliegenden Arbeit wertvolle Informationen zur Verbesserung des Portfolio Management finden.

Projekt Portfolio Management beinhaltet eine Menge von Prozessen, die der bestmöglichen Projektauswahl eines Unternehmens dient. Die vom Unternehmen durchgeführte Auswahl von Projekten, die Koordination dieser Projekte und periodisch wiederkehrende Reviews bezüglich der Projektauswahl, sind Hauptaufgaben des Portfolio Managements. Strategische Ausrichtung, effiziente Nutzung von Ressourcen und ausgeglichene Portfolios bezüglich des Risikos sind die Hauptziele von Projekt Portfolio Management. Die Auswahl von Projekten ist eine komplexe Aufgabe, da verschiedenste Ziele, Restriktionen, Bedingungen und subjektive Präferenzen beachtet werden müssen. Die Komplexität wächst mit der Projektanzahl aus denen eine Auswahl getroffen werden muss.

Die vorliegende Diplomarbeit präsentiert ein Entscheidungs-Unterstützungs-Rahmenwerk, welches auf die automatisierte Auswahl von Projekten abzielt und hierfür einen sogenannten evolutionären Optimierungs-Algorithmus nutzt. Im ersten Teil wird eine Implementation des Optimierungs-Algorithmus für dieses Problem präsentiert. Das daraus resultierende Optimierungsprogramm ist fähig innerhalb weniger Minuten effiziente Portfolios zu erstellen, welche im Sinne der Mehrzieloptimierung besser sind als sonstige im Lösungsraum vorhandene Portfolios. Diese Auswahl wird die Pareto-Optimale Front genannt. Im zweiten Teil wird ein Gruppen-Entscheidungs-Prozess vorgestellt, der eine Gruppe von Entscheidungsträgern bei der Auswahl eines Portfolios aus der Pareto-Optimalen Front unterstützen soll.

Hauptbeitrag dieser Diplomarbeit ist die Kombination eines objektiven Optimierungs-Projekt-Auswahl-Rahmenwerks mit einem einfach zu bedienenden Gruppen-Entscheidungs-Prozesses, in welchem individuelle Präferenzen visualisiert werden können und die Suche nach Konsens bezüglich unterschiedlicher Präferenzen erleichtert wird. Der präsentierte Ansatz zur Portfolio-Optimierung erhält besondere Relevanz, da diesbezüglich eine neue Methode zur Auswahl und Anordnung von Projekten beschrieben wird. Weiters werden hierfür Methoden zur Optimierung von Portfolios bezüglich verschiedenster objektiver Präferenzen wie Risiko Verteilung vorgestellt. Dabei werden zahlreiche Restriktionen, Bedingungen und logische Abhängigkeiten beachtet. Der vorgestellte Optimierungsansatz schränkt die zu optimierende Projektanzahl nicht ein.

**Abstract.** Multi-Objective Optimisation, Group Decision Support and Visualisation are the major fields of research in this thesis. The optimisation part deals with solving the demanding project selection problem, especially focusing on selecting software development projects. The fields of Group Decision Support and Visualisation are addressed by creating a portfolio selection process, applicable to group decisions, supported by visualisation and data exploration techniques. Students and researchers interested in the field of optimisation, especially with evolutionary algorithms, project portfolio management in general, and group decision support, are the main audience of this thesis. Managers and consultants can find practical and valuable information to improve the project portfolio management of an organisation.

Project Portfolio Management is a set of processes used to support a business in conducting the mix of projects, which best fit the organisation's various needs. This set of processes includes the selection of projects an organisation conducts, maintaining the selected projects in portfolios, and periodically reviewing the mix of projects, to check whether the selection still supports the main business goals. Strategic alignment of the selected projects, efficient use of scarce resources, and balanced portfolios regarding risk and category alignment, are among the main goals of Project Portfolio Management. The selection of projects is a complex task, since numerous goals, restrictions, constraints and subjective preferences have to be taken into account. The complexity grows exponentially with the number of projects to select.

In this thesis a two-phase decision support framework is presented, which focuses on the selection of projects, using an evolutionary optimisation algorithm. In the first phase, an implementation of a mathematically based optimisation framework is presented, using the evolutionary algorithm mPOEMS, based on general goals which the portfolio management should support. This optimisation framework is able to find efficient portfolios on the pareto-optimal front. In the second phase, a decision support process for the selection of one portfolio out of the pareto-optimal front is presented, especially designed to be applicable to a group of decision makers.

A comparison of the presented optimisation approach using mPOEMS, with the two state-of-the-art optimisation algorithms NSGA-2 and SPEA-2, shows that mPOEMS performs better in two out of three multi-criteria optimisation metrics. The main contribution of this thesis is the combination of an objective optimisation project selection framework, with an easy-to-use group decision process, in which individual preferences can be visualised and the search for consent in subjective preferences is facilitated. The presented evolutionary approach to portfolio optimisation is especially meaningful, because a new method about how to deal with the sequencing of projects is outlined. Methods are presented to optimise portfolios with respect to certain objective preferences like category assignment and risk distribution, the consideration of numerous restrictions, constraints and logical dependencies. The presented approach is theoretically not restricted in the number of projects it can deal with.

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
<b>2</b>	<b>Related Work</b>	<b>5</b>
2.1	Project Management . . . . .	6
2.1.1	Project Scope Management . . . . .	9
2.1.2	Project Time Management . . . . .	11
2.1.3	Project Risk Management . . . . .	13
2.1.4	Project Cost Management . . . . .	14
2.1.5	Project Integration Management . . . . .	16
2.2	Project Management in IT Projects . . . . .	17
2.2.1	COCOMO II . . . . .	17
2.2.2	Software Project Risk Level Quantification . . . . .	21
2.3	Program Management . . . . .	22
2.4	Project Portfolio Management . . . . .	27
2.5	Project Portfolio Management Processes . . . . .	30
2.5.1	Strategy . . . . .	34
2.5.2	Identification . . . . .	36
2.5.3	Categorisation . . . . .	37
2.5.4	Evaluation . . . . .	38
2.5.5	Selection, Prioritisation and Balancing . . . . .	47
2.6	Mathematically based portfolio optimisation . . . . .	48
2.7	Evolutionary Algorithms . . . . .	49
2.7.1	mPOEMS . . . . .	52
2.8	Visualisation of multi-dimensional data . . . . .	54
<b>3</b>	<b>Research Issues</b>	<b>57</b>
3.1	Collaborative Interactive Decision Support . . . . .	58
3.1.1	Research Issue One: Feasibility of the CIDECS Process . . . . .	58
3.2	General Goals of Portfolio Optimisation . . . . .	60
3.2.1	Research Issue Two: Preparation of the Business Environment . . . . .	61
3.2.2	Research Issue Three: Generic Model . . . . .	62
3.2.3	Research Issue Four: Optimisation Goals regarding Sequencing/Synergy . . . . .	62
3.3	Evolutionary Algorithms . . . . .	63
3.3.1	Research Issue Five: Feasibility of mPOEMS . . . . .	63
3.3.2	Research Issue Six: Adapt mPOEMS to Portfolio Optimisation . . . . .	64
3.3.3	Research Issue Seven: Performance of mPOEMS . . . . .	64
3.4	Group Decision and Visualisation . . . . .	64

3.4.1	Research Issue Eight: Group Decision Process . . . . .	65
3.4.2	Research Issue Nine: Visualise multi-dimensional data . . . . .	65
3.4.3	Research Issue Ten: Insertion of Individual Preferences . . . . .	65
<b>4</b>	<b>Approach</b>	<b>66</b>
<b>5</b>	<b>Decision &amp; Goal Model</b>	<b>69</b>
5.1	The Project Portfolio Management Process . . . . .	69
5.1.1	Strategy Ranking . . . . .	69
5.1.2	Set Key Criteria . . . . .	70
5.1.3	Submit Projects . . . . .	71
5.1.4	Set Preferences . . . . .	71
5.1.5	Screening . . . . .	72
5.1.6	Set Constraints . . . . .	72
5.1.7	Create Efficient Portfolios . . . . .	73
5.1.8	Choose Portfolio . . . . .	73
5.1.9	Make Manual Adjustments . . . . .	74
5.1.10	Execute Projects . . . . .	74
5.2	Mathematically based portfolio optimisation . . . . .	74
5.2.1	Formal Model . . . . .	74
<b>6</b>	<b>Alternative Generation &amp; Reduction</b>	<b>81</b>
<b>7</b>	<b>Research Evaluation Framework</b>	<b>84</b>
7.1	Test Data . . . . .	84
7.1.1	Cost and Schedule Generation . . . . .	85
7.1.2	Starting Months Generation . . . . .	87
7.1.3	Potential Revenue Generation . . . . .	88
7.1.4	Category Membership Generation . . . . .	88
7.1.5	Strategic Alignment Generation . . . . .	88
7.1.6	Synergy Effect Generation . . . . .	89
7.1.7	Interdependencies Generation . . . . .	89
7.1.8	Risk Generation . . . . .	90
7.1.9	Mutually Exclusive Projects Selection . . . . .	90
7.1.10	Mandatory Projects Selection . . . . .	90
7.1.11	Testset Configuration Values . . . . .	90
7.1.12	Portfolio Data Creation . . . . .	91
7.2	Solution Quality Criteria . . . . .	91
7.3	Test Runs - Computation and Analysis . . . . .	92
7.3.1	Testset . . . . .	93
7.3.2	Results of mPOEMS . . . . .	97
7.3.3	Results using PISA . . . . .	99
7.3.4	Comparison NSGA-2, SPEA-2, and mPOEMS . . . . .	101
<b>8</b>	<b>Interactive Visualisation &amp; Discussion</b>	<b>106</b>
8.1	Group Decision Process . . . . .	106
8.1.1	Preference Function . . . . .	106

8.1.2	Decision Rules . . . . .	108
8.2	Visualisation . . . . .	110
<b>9</b>	<b>Discussion</b>	<b>122</b>
<b>10</b>	<b>Conclusion</b>	<b>131</b>
	<b>References</b>	<b>137</b>
	<b>List of Figures</b>	<b>139</b>
	<b>List of Tables</b>	<b>141</b>
	<b>List of Abbreviations</b>	<b>143</b>



# 1 Introduction

The main goal of this thesis is to create a framework for a decision support system in the field of Project Portfolio Management (PPM). PPM is a set of processes used to support a business in conducting the mix of projects, which best fit the organisation's various needs. This set of processes includes the selection of projects an organisation conducts, maintaining the selected projects in portfolios, and periodically reviewing the mix of projects, to check whether the selection still supports the main business goals. Various portfolio processes have already been presented. Most of them do cover the whole life cycle of portfolios, from selecting projects and optimising portfolios to phase gate review steps [1] [37].

Portfolio optimisation is a process in PPM that create the best mix of projects, out of all potential candidates. Selection of projects, and optimisation of projects can be conducted either manually or automatically. Manual approaches to select projects are for example AHP, Q-Sort, scoring models, and portfolio matrices. Commonly manual approaches are based on some sort of direct comparison and ranking of the alternatives based on project data and individual preferences. Manually conducting the selection of projects is restricted in the number of projects it can deal with, constraints and objective preferences which can be taken care of, as well as the number of objectives the decision makers are able to optimise. This is especially true, since the complexity grows exponentially with the number of available project alternatives [14]. The project selection problem is actually considered in [14], as a Non-deterministic, Polynomial-Time hard problem.

The complexity of the project selection problem is based on the often high number of projects from which a subset has to be chosen, various existent restrictions and a multitude of objective preferences which the optimal portfolio should adhere to. Common goals of portfolio optimisation are maximisation of potential revenue and strategic alignment, as well as minimisation of negative synergy effects in-between projects selected for a portfolio. Furthermore, portfolios often have to be balanced regarding characteristics of the portfolios. These balancing requirements are found in the number of projects assigned to a specific category, or in the optimisation of a portfolio regarding its overall mean risk value.

Manual approaches to this demanding decision problem are restricted in their useful-

ness for the problem at hand. Promising alternatives to manually selecting projects are found in the field of mathematically based portfolio optimisation, and multi-objective optimisation. Automated approaches are superior to manual approaches in a way that they are able to create a set of efficient portfolios, for which it can be assured that there exist no solutions in the search space which promises higher values in at least one of the objectives, and offers at least the same in all the others. This set of efficient solutions is commonly referred to as the pareto-optimal front. Furthermore, the utilised computational power and sophisticated multi-objective meta-heuristics ensure that the solutions found do have at least the same quality as manually created portfolios. With a high probability, solutions on the pareto-optimal front found by automated approaches are much better than solutions found with manual approaches. Furthermore, manual approaches will never be able to keep up with the search ability of automated approaches, and the number of considered objectives, restrictions and constraints. For example, the presented evolutionary approach to portfolio optimisation samples 150,000 solutions in approximately three minutes.

Various presented approaches have proven that integer linear programming models [42], pareto ant colony optimisation [14], and genetic algorithms Medaglia are generally applicable to the project selection problem. The decision to apply an evolutionary algorithm to the project selection problem is inspired by these papers. The presented optimisation frameworks do mostly embed the mathematically based search for the pareto-optimal front, into some kind of decision support system to select one portfolio out of the pareto-optimal front, which is, in turn, considered as a complex decision problem. The decision which projects an organisation conduct is mostly conducted by a group of decision makers. Nevertheless, none of the investigated papers do present a process to embed this decision problem into a group decision process. Furthermore, the papers from Archer [16] and Stummer [42], call for the adaptation of the presented decision support systems to group decisions in the future work section.

In this thesis, a two-phase decision support framework is presented, which focuses on the selection of projects, using an evolutionary optimisation algorithm. In the first phase, an implementation of a mathematically based optimisation framework is presented, using the recently published evolutionary algorithm mPOEMS. In the second phase, a decision support process for the selection of one portfolio out of the pareto-optimal front is presented, especially designed to be applicable to a group of decision makers.

The implementation of the mathematically based optimisation framework is based on a detailed investigation of the corresponding theory, and is influenced by already published portfolio optimisation approaches. The literature research and presentation of all related

work in chapter 2, lead to a list of goals a realistic model of the portfolio environment has to support. This list is presented in section 3.2. A process to prepare the business environment for the step of mathematically based portfolio optimisation is presented in section 5.1, based on the list of PPM goals. This process shows the steps one has to conduct to be able to use the presented optimisation approach. The optimisation approach is presented in the sections 5.2.1, and 6. At first a formal model of the portfolio optimisation environment is created. This formal model presents the approach to solve the project selection problem, including implementation details like the solution representation. Furthermore, the formal model presents the mathematical foundation that deals with the various portfolio optimisation characteristics, like revenue maximisation, negative synergy minimisation, project sequencing and resource usage optimisation, objective preferences balancing, and logical constraints. Chapter 6 shows how the way, how the previously created generic JAVA implementation of the evolutionary algorithm mPOEMS [24] can be adapted to solve the project selection problem, defined in the formal model.

Results of the implemented evolutionary approach to project selection are presented in the research evaluation framework in chapter 7. Test runs are conducted on a test set with fifty software development projects. This chapter also includes the presentation of how project data could be generated and adjusted in order to use them for the portfolio optimisation approach, based on the cost estimation framework COCOMO II. Furthermore, the performance of mPOEMS is compared with results found by the state-of-the-art search and optimisation algorithms NSGA-2 and SPEA-2.

The group decision support process for the selection of one portfolio out of the pareto-optimal front is presented in chapter 8. The core of the presented group decision process is a decision model, including decision rules and preference functions, which reduce the evaluation of an alternative to an analytical operation [28]. Visualisation and data exploration techniques are presented to guide a group of decision makers through the process of finding consent in their individual preferences. The search for consent is conducted by calculating subjective preference values for each portfolio, and encoding these values as colour and size in the visualisations used. Thus decision makers are given an easy-to-use tool to search for a portfolio candidate which fits all individual preferences, by choosing portfolios based on the colour and size of the corresponding visualisations. The used data exploration tool enables the decision makers to playfully explore the decision space, while visually providing all needed portfolio and project data.

The main contribution of this thesis, is the combination of an objective optimisation project selection framework, with an easy-to-use group decision process, in which indi-

vidual preferences can be visualised and the search for consent in subjective preferences is facilitated. It is shown that the evolutionary algorithm mPOEMS is able to solve the demanding project selection problem. The presented evolutionary optimisation project selection framework is especially meaningful, because it presents some new ideas to deal with project selection in a mathematically based optimisation framework. Among them is the expansion of the commonly used 0-1 solution representation vector, to a *0-possible starting timeframes* solution representation vector, enabling the used evolutionary algorithm not only to optimise portfolios regarding the selected projects, but also to select the starting timeframe of the projects, out of the list of possible starting timeframes of each project. Thus, the proposed approach is able to conduct optimisation in the sequencing of projects. Also an interesting contribution to this field is the introduction of so called soft preferences. Soft preferences are objective preferences like, for example, the number of projects assigned to a specific category, or the overall mean risk value of portfolios. There is no need to create portfolios only with, for example, exactly fifteen projects assigned to category three. But there often exist objective preferences, which do want the optimisation of portfolios to consider such a preference as another goal to optimise. This can be achieved in using soft preferences. Soft preference functions return a value, based on the portfolio's adherence to the soft preference, which is either maximised or minimised, thus creating selection pressure towards portfolios which adhere to the defined soft preferences. The quality of the presented optimisation approach is especially based on the combined number of tools an optimisation project selection engineer can use with the proposed approach. These tools are maximisation, minimisation, soft preferences, resource restriction/optimisation, and the support of logic constraints, like project dependencies.

The next chapter presents all related work of this thesis, followed by the presentation of the research issues. Chapter 4 presents the approach to answer the research issues.

## 2 Related Work

This section summarises work on related topics of the thesis presented, as the foundation for my research on Project Portfolio Decision Support using Evolutionary Algorithms.

Related work is found in the topics project management, program management, project portfolio management in general, project portfolio management processes in particular, mathematically based portfolio optimisation, and the topic of visualisation of multi-dimensional data. The next paragraph introduces the reader into the field of project portfolio management, followed by the presentation of all related topics in detail.

Project Portfolio Management PPM provides medium- to long-term strategic and operational direction for a business. A direction which can lead an organisation into prosperous or demanding times. Having chosen and conducted the "wrong" projects, has a great and direct impact on the benefits of a company. It is unquestioned that PPM is of main importance for any company, especially true for medium- to large-sized companies. Small sized companies will use PPM as well, but probably not to the extent and necessity of bigger companies, because of the lack of a great amount of possible initiatives and rather in an informal setting. Having available a great amount of possible initiatives lead directly to the question of which initiatives should be chosen. Furthermore the question arise of how decision makers can choose one project over another. Which are the characteristics of an initiative taken into account in the selection process? Does the organisation have a strategic direction and in which degree is the strategy supported by a specific initiative? How to attain a sane balance between estimated return and overall portfolio risk, whilst meeting stakeholders' risk preferences? These questions, combined with various restrictions, e.g. time and resources, create a challenging NP-hard problem, with a huge alternative solution space.

PPM deals with this NP-hard problem, and supports the process of choosing the "right " projects, combined with the management and control the projects in a defined and centralised way [37].

PPM cannot be successfully conducted without profound knowledge about project management, and a mature project management mechanism, including cost and risk estimation. This is because PPM uses the project inherent characteristics to make decisions for the overall portfolio, hence project data provides an indispensable part of the knowledge base for PPM. Therefore, the next section presents a theoretical and general description of the broad field of project management. Techniques and methods are presented to conduct parts of the planning phase.

The management of programs is also an indispensable part of PPM. Program management deals with the management of a subset of projects of a portfolio which are grouped together. This grouping is conducted to ease the management of inter-related projects, sharing common goals and/or resources. Section 2.3 presents the theoretical background for program management.

Section 2.4 presents the PPM in detail, including descriptions of the conjunction with project and program management, followed by a presentation of generally applied PPM processes in section 2.5.

The following sections do mark especially important information as goals. The goals are listed in section 3.2 to provide an overview of goals which a preferably realistic portfolio optimisation process should support.

## 2.1 Project Management

According to Reyck [39], organisations at the lowest level of PPM adoption, face problems with commitment of business leaders, poor alignment of projects to strategy, little coordination between projects and conflicting project objectives. This situation is on the one hand created by poor PPM, on the other hand a result of a lack of relevant training and appropriate knowledge, which is needed to measure project benefits [39]. An organisation struggling with the appliance of project management will more likely try to improve project management, than move to the next organisational level, which is called PPM.

Organisational strategy, involvement of top executives, financial and strategy team skills are the pre-conditions for PPM defined by Reyck [39]. We will see that the project management processes are strongly interdependent. Thus the need for financial and strategy team skills leads directly to the need for profound knowledge in the entire field of project management, and as well to the demand for mature project management processes.

There is a great consensus, in scientific and economic communities, supporting the

positive effects of applied project management. Kerzner [23] reveals a bunch of positive outcomes in applying project management. The following listing shows some of these outcomes:

- Increase of quality
- Increase of profitability
- Identification of time limits for scheduling
- Improved estimating capability for future planning
- Project management provides a means for solving problems
- Project management leads to more conducted work in less time
- Early identification of problems so that corrective action may follow
- Identification of functional responsibilities to ensure that all activities are accounted for, regardless of personnel turnover

Even though this listing is just a digest, it shows the potential of project management. Besides the literature, investigations have shown the positive effects of project management. A positive relation between the level of adoption of project management techniques and improvements in performance, concerning schedule and cost, was proven by Ibbs [19]. Another study, conducted by L. Patah [36], tried to measure the value of project management in financial terms. The investigation of more than 150 projects in the German electrical industry led the author to the conclusions, that each US Dollar spent in project management methodologies resulted in a gain of 9.6 US Dollars. This significant number will probably diminish in other investigations, nevertheless it supports the literature in the proposition of positive outcomes of applied project management.

Definitions of the term *project* usually contain, in some way, the adjectives *temporary* and *unique*. The Project Management Institute (PMI) defines a project in [15] as

"a temporary endeavour undertaken to create a unique product or service."

Kerzner [23] defines a project as any series of activities and tasks that:

- Have a specific objective to be completed within certain specifications
- Have defined start and end dates
- Have funding limits

- Consume human and nonhuman resources (e.g. money, people, equipment)
- Are multifunctional (e.g. cut across several functional lines)

The planning and monitoring of such constructs is commonly known as project management. It comprises the utilisation of knowledge, skills, tools, and techniques to meet stakeholders needs [15]. Project management helps to address the project objectives and stakeholder's needs within time, cost and quality specifications [23]. Moreover, dealing with, and effective use of restricted resources is a main part of project management.

Project management is commonly divided into five process groups and corresponding knowledge areas [15]. Figure 2.1 shows these groups and their relationship.

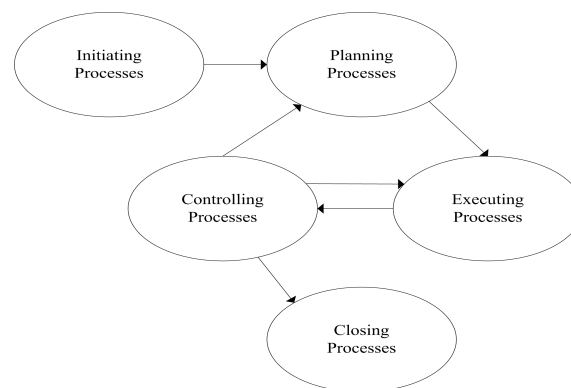


Figure 2.1: Links Among Process Groups; Source: [15]

The initiating process executes the beginning of a project, the planning process group provides a scheme to meet the business needs underlying the project, the executing process group covers all the coordination to carry out the project plan, the controlling process contains the processes for monitoring and measuring progress, and the closing process group brings the project to a well structured and documented end [15]. A successful execution of a project mostly needs a few iterations over the planning, executing and controlling processes, since assumptions made in the planning process and the project environment continuously change.

The major responsibility of the project manager, the person in charge of the project, lies in planning, integrating and executing plans. Planning is a methodically, continuous approach to making entrepreneurial decisions, with respect to the future and the effort needed to carry out these decisions [23].

This introduction into the field of project management will mainly present the planning process group. To a lesser extend because of the major importance of planning for project management, but mainly because of the thesis' focus on the presentation of a PPM process, which need some input data from the project management planning process group.



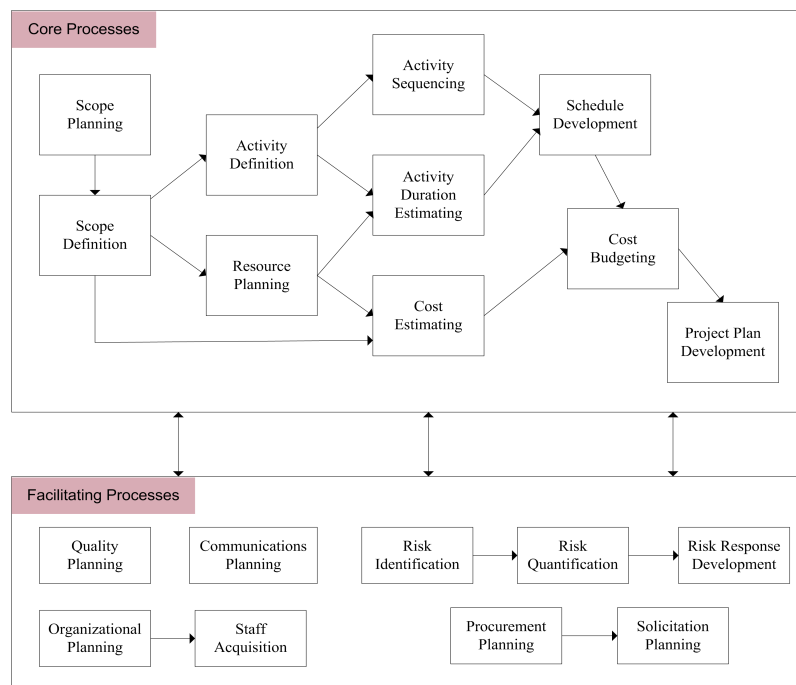


Figure 2.2: Planning Process Group; Source: [15]

Figure 2.2 shows the planning process group and all the comprised processes, grouped into core and facilitating processes. The introduction will cover all of the core processes and selected facilitating processes. The selected facilitating processes are Risk Identification and Risk Quantification. Especially important processes for this thesis will be presented not only in general terms, but particularly focused on IT software development projects. These processes are software development cost estimation, and risk definition. The presented processes are grouped into their corresponding knowledge areas.

### 2.1.1 Project Scope Management

Project Scope Management deals with the definition of what is included in the project and what is excluded from the project [15]. its major objective is to create four documents which answer the questions: who, what, when, why, where, how, and how many. These documents are by definition: Scope, Project Scope, Scope Statement and Statement of Work. The Scope element comprises all products, services and results, which are part of the project. The Project Scope element defines all the work that has to be carried out in order to create all products, services and results. The Scope Statement element is an attempt to achieve common understanding of the project scope, including description of the objectives, deliverables and project justification. The Statement of Work is mostly created by the customer. It notes the high-level requirements of a project in sufficient

detail, to allow a prospective seller to provide a bidding [23].

Accurately conducted Project Scope Management is of major importance, because improper defined project scope will definitely lead to higher cost and probably unsatisfied customers.

In the planning phase of a project two major scope management process exist. These are Scope Planning and Scope Definition.

**Scope Planning** A product description notes the characteristics of the project's product or service. Either a product description, or a statement of work serve as input to the scope planning process. If the buyer's work involves not only a product, but also covers a whole project, a statement of work is used. A project charter, which formally defines the project existence, identified constraints and various assumptions serve as well as input to the planning process.

Based on the defined characteristics of the products and services included in the project, a product analysis may be conducted, in order to gain deeper insight into the project-inherent requirements. Searching for alternative approaches and a cost/benefit analysis should lead to a sequence of the identified alternatives.

The most appealing alternative will be described in detail by the revised product statement, project deliverables, project objectives as well as the project justification, to illustrate the business need of the project. Those elements together are commonly considered as the scope statement, providing stakeholders with a common understanding and acting as a documentation for future project decisions [15].

**Scope Definition** The decomposition of major project deliverables, defined in the scope statement together with the project requirements, is conducted in the scope definition process. In order to develop adequate cost and duration estimates, the project is subdivided into more manageable components. The outcome of this process is a work breakdown structure (WBS). Further planning, executing, controlling and closing will be carried out on the basis of the WBS. The WBS comprises the total scope of the project, in which lower levels of the WBS display a more detailed description of the project elements [15].

Kerzner [23] states that the WBS is the most important project planning element, covering the following features:

- The whole construct can be discovered as a sum of all subdivided elements
- Planning can be conducted
- Cost and budgets can be created

- Tracking of time, cost and performance is possible
- Logical linking of objectives to company resources
- Schedule and status reporting possibilities
- Responsibility can be assigned to each element

A very common, six-level indented WBS like that presented in [23] is shown below. It sketches the decomposition of programs into projects and projects into tasks:

<i>Managerial levels</i>	<i>Description</i>
1	Total program
2	Project
3	Task
<i>Technical levels</i>	
4	Subtask
5	Work package
6	Level of effort

### 2.1.2 Project Time Management

The processes, part of Project Time Management, aim to assure the timely completion of the project. Therefore, activities based on the WBS have to be defined to conduct all of the required work. These activities will be linked and resources allocated. After having defined all of the needed activities, the duration of each activity will be estimated. The outcome of these processes is an overall project schedule with defined start- and end-dates. Completing the project in the best time, with the least cost and the least risk, are the three primary goals of a project schedule. Secondary goals comprise the development of an optimal schedule, effective use of resources, refinement of the estimating criteria and obtaining project control [23].

**Activity Definition** First and foremost, the process Activity Definition works out all the works activities needed to produce the project deliverables. The WBS, together with the scope statement, project-related constraints and assumptions, are used as input for this process. Using the WBS helps to address the need to cover all of the project requirements, and help to define all activities needed to conduct the project successfully.

The output of this process is a list of activities, which should be performed in the project. It is of special importance, that the activity list is linked to the WBS in a logical manner [15]. Integrity and the exclusion of non-project-related activities can be assured

in this way. This could be done by using the numbering of the WBS for the activity list. Potential discovery of work which was not included in the WBS should lead to an update and refinement of the WBS.

**Activity Sequencing** The more or less unordered list of activities will be put in order in this process. After an investigation of the product's description and various dependencies, the activities will be related to each other, considering activity interdependencies. Dependencies could originate from product characteristics. As an example let's imagine a software development product where module A should communicate with module B. Module A can probably not be finished, before module B publish its interface. The activity sequencing has to consider such dependencies. Non product-related are such dependencies as physical limitations, best practises of project teams and the delivery of a needed hardware at a specific date. Techniques for activity sequencing for example, are the *precedence diagramming method* and the *arrow diagramming method*, in which both directed graphs are applied to the sequencing problem [15].

**Activity Duration Estimating** Based on the list of activities, resource requirements and resource capabilities, an estimate of the needed work effort is created for each activity [15]. The process of estimating the duration of activities is often connected with a high degree of uncertainty, therefore inherently risk-afflicted. The degree of uncertainty is directly connected with the experience of the project manager, the quality of the activity description and the quantity and respective quality of available historical data.

The outcome of this process is duration estimates, combined with an indication of the range or likelihood of the estimates accuracy [15].

**Schedule Development** This process expands the idea of the activity sequencing process by adding start and finish dates to the activities of the project network diagram. It takes into account the duration estimates of each activity, the resources each activity requires and the availability of these resources. The availability of resources and calendars has a great influence on the schedule development. In most projects either the customer imposes certain deadlines for delivery, or market circumstances force the project to be finished before a certain date [15].

Critical Path Method (CPM), Graphical Evaluation and Review Technique (GERT) and the Program Evaluation and Review Technique (PERT) are some of the techniques frequently used for schedule development. These techniques help the management in various ways [23].

The outcome of this process is a project schedule, often displayed in the form of a Gantt chart.

### 2.1.3 Project Risk Management

In the planning phase the Risk Management knowledge area deals with Risk Identification and Risk Quantification. Considered as facilitating processes, these processes have influence on the core processes, especially on the cost planning process.

Risk is defined by Kerzner [23] as

"a measure of the probability and consequence of not achieving a defined project goal."

Therefore, risk can be regarded as a function of likelihood and impact. Risk generally increases, if either likelihood or impact rises. Furthermore, the relationship between probability and impact has to be understood. A risk, which occurs with a probability of 0.70 and an associated damage of, let's say, 100 EUR, is considered probably less serious than a risk with a probability of 0.05 and an associated damage of 100,000 EUR.

It is of major importance that the project management identifies possible risks, their causes and their effect on the project, whereas the use of a repeatable and structured risk identification process is recommended, assuring certain and accurate results [23].

**Risk Identification** This process takes into account the product description and the various planning outputs. In order to identify risks which are likely to affect the project. Product inherent characteristics should be analysed in order to assess how realistic the requirements are, how likely they will change and how uncertain the product-related assumptions are. Fields of investigation, which should be covered as well in this identification process, are the WBS, cost and duration estimates, the staffing plan and historical information [15]. Not only these artefacts could be used for risk identification, but any source of information potentially useful for this process could also be utilised. These sources are, for example, [23]:

- Brainstorming
- Checklists
- Expert judgement
- Systems engineering documentation
- Technology analysis

Based on an investigation of the WBS, supported by an expert, the risk of a software development project could be the relative inexperience of the project team in applying a specific software development technique.

The output of this process should cover all the potential risks, sources of risk and identified triggers that could lead to a risk event.

**Risk Quantification** This process is often referred to as Risk Analysis. Regardless of the name, this process estimates the level of risk for already identified risk issues. Based on the estimated likelihood of occurrence and the consequences of occurrence, corresponding risk levels are determined. These risk levels are an indication of the risk's potential impact on a project [23]. The output of this process is a list of risks that should be monitored.

### 2.1.4 Project Cost Management

This knowledge area deals with the cost planning and control in projects. Based on a detailed investigation of the needed resources, the cost for conducting all of the required work is estimated. A baseline of the budget is the main output of this process in the planning phase.

Besides the effort-cost estimating, cost management often includes techniques to predict and analyse the prospective financial performance of the project [15]. The desirability of a project is often measured in terms of these financial key figures. These figures include Return-On-Investment (ROI), Net Present Value (NPV), Discounted Cash Flow and Payback Analysis.

**Resource Planning** This process comprises the planning of potentially needed physical resources to conduct all of the needed work. The WBS is taken as a reference to ensure that all planned work is reconsidered in the resource planning process. Historical information can help in identifying which type of resources was required to conduct specific work in the past. This is of special importance to consider which resources are potentially available, either within inside the company or from consultants.

Output of this process is a description of the required resources for each WBS element [15]. The lower the level of the WBS used for this investigation, the more likely is the accuracy of the results.

An approach to improve and support decision makers in resource management is presented in [17]. This paper shows the utilisation of a genetic algorithm, which is a particular class of evolutionary algorithms to optimise project resource allocation and levelling.

**Cost Estimating** The unit rate for each resource, together with the resource quantity needed, form the basis for calculating the cost estimates. Staff costs could be determined by information exchange with the department manager or the accounting department. The duration estimates of each activity influence the approximated quantity needed to conduct a work, and are therefore of major importance.

Techniques to estimate the cost are the so called *Analogous estimating*, where similar projects are taken as a reference for estimating, and *Bottom-up estimating*, where the cost of each individual work item is estimated. Promising approaches are mathematical models, developed for specific project types, which use project characteristics as parameters to calculate project costs [15].

**Cost Budgeting** The last step of the planning phase in cost management allocates the estimated costs to individual work items. Output serves a cost baseline which specifies for each phase of the project, the budget and can be used to monitor cost performance [15].

**Two financial metrics - NPV and ROI** The NPV is a financial figure to evaluate projects with regard to their potential financial outcome. It relates the current value of future value inflows, to the initial investment. Therefore, a NPV less than zero is a sign that the financial benefits of a project do not cover the financial expenses. The following equation presents the formula to calculate the NPV.

$$NPV = \sum_{t=1}^n \left[ \frac{FV_t}{(1+k)^t} \right] - II \quad (2.1)$$

The future values (FV) are discounted to a specific date by a rate (k), equal to the firm's cost of capital, and the initial investments (II) are subtracted in order to get the NPV [23].

The ROI metric relates the outcome subtracted by the costs of the project to the investment the project require. This metric presents the financial efficiency of an investment. A general definition of this metric is presented by the following equation, where RI is the potential revenue of the investment, and CI is the potential cost of investment.

$$ROI = \frac{(RI - CI)}{CI} \quad (2.2)$$

A common approach is to divide the NPV of all potential incomes by the cost of all resources that have been used for this project.

A negative ROI is an indicator for an investment which is better not undertaken from a financial point of view, and the higher the ROI, the more promising is the investment.

### 2.1.5 Project Integration Management

This knowledge area deals with processes that are primarily integrative. The Project Plan Development process merges the outputs of the planning processes into one document. This plan provides both a project guideline and a basis to measure project performance against requirements.

**Project Plan Development** Since the project environment is subject to steady change, this process has to be iterated several times. Information about changes in one project management process, has to lead directly to an update in the project plan. The project plan is a formal document, used as a standard communications tool throughout the whole project life cycle [23]. It commonly includes the following items [15]:

- A project charter
- Project Management approach
- Scope statement
- The WBS
- Cost estimates
- Measurement baselines for schedule and cost
- Schedule
- Activity list and their interrelationships
- Milestones
- Staffing information
- Risk Management Plan
- Open issues and pending decisions

The project plan should be available to all personnel involved in the project, and answer the following questions [23]:

- What will be accomplished?
- How will it be accomplished?
- Where will it be accomplished?



- When will it be accomplished?
- Why will it be accomplished?

## 2.2 Project Management in IT Projects

The previous section presents the planning processes in project management in general. This section introduces selected project planning processes for software development projects. The COCOMO II (Constructive Cost Model) framework for carrying out cost estimation is presented first, followed by a method to quantify the risk value of software projects.

### 2.2.1 COCOMO II

Estimating costs of a software development project is influenced by various parameters. Development environment, developer experience, requirements stability, development process and required reliability of the software are just some of the factors significantly influencing the cost of a software project.

COCOMO II (Constructive Cost Model) is a framework for software project cost and schedule estimation, and provides the user with tools for estimating the likely cost, effort and time needed to conduct a software project [4]. The framework consists of a collection of equations and constants derived from a project database, and a variety of parameters for adjusting the model to various circumstances.

This framework can be used to make investment decisions to create project budgets and schedules, and to conduct sensitivity analysis, regarding rate of reuse, staffing, schedule and so on.

Three phases are distinguished within this model. Early prototyping, early design, and post architecture are phases that differ in their amount of available and reliable information. The early prototyping phase is characterised by efforts to resolve potential risk issues such as user interfaces, performance and technology maturity. In the early design phase, enough information is available to define the software and system architecture, and the concepts of operation. The life-cycle architecture is defined in the post architecture phase, enough information to create accurate cost estimates is available, and the model support this phase with a comprehensive set of parameters [5].

In the process of proposing projects for a portfolio, enough information should be available to conduct a high level estimate. Therefore, the steps of the COCOMO II model to create estimates in the early design phase are presented. Sizing and Effort Estimation are the two COCOMO II steps which have to be conducted in order to create an estimate.

**Sizing** The project size predominantly determines the cost of a software project. Source Lines of Code (SLOC) or Function Points (FP) are used to describe the size, whereas the FP are converted to SLOC, because the equation to calculate the effort uses SLOC as an input parameter. SLOC of a software project can be estimated either in using historical data, or with the help of experts. The goal is to measure the intellectual work that will be put into the program development [4].

FP measure the functionality of a software project. Four steps are conducted to determine the unadjusted FP. First the number of each function type has to be counted, whereas five FP classes of function types, External Input, External Output, Internal Logical File, External Interface Files, and External Inquiry, are distinguished. These classes define the information processing functionality concerning different input, output and file types. Secondly, each function type will be classified into low-, average- and high-complexity levels. In the third, step the function types will be weighted and a number assigned, based on the class and complexity level of the function type under consideration. The last step accumulates these numbers and the result is the number of unadjusted function points. The conversion from FP to SLOC is conducted with the help of conversion ratios, relating a development language to a FP / SLOC ratio [4]. For example, the development language Java is listed with a ratio of fifty-three SLOC per FP.

**Effort Estimation** The effort needed to conduct a software development project is specified in PM (Person Months). Equation 2.3 shows the COCOMO II effort estimation model for calculating the effort in PM.

$$PM = A \cdot Size^E \cdot \prod_{i=1}^n EM_i \quad (2.3)$$

So far, the only variable known is the *Size*, presented in the preceding paragraph. *Size* enters the equation in Thousands(K) of Source Lines of Code (KSLOC). *A* is a constant that approximates the productivity  $PM / KSLOC$  of the organisation. *A* should be adjusted to local settings, and has the value of 2.94 in the initial calibration of COCOMO II.

The exponential factor *E* defines the economies ( $E < 1.0$ ) or the diseconomies ( $E > 1.0$ ) of scale. If the size of a project is doubled, and the exponential factor *E* is less than 1.0, the effort is less than doubled, and thus the project exhibits economies of scale. *E* is calculated following the equation 2.4, and is the sum of the constant *B*, and the sum of five different scale factors (SF), multiplied with 0.01.

$$E = B + 0.01 \cdot \sum_{j=1}^5 SF_j \quad (2.4)$$

$B$  is set to 0.91 in the initial calibration of COCOMO II and should be adjusted to local circumstances. Table 2.1 presents the five SF, where Precedentedness is abbreviated with PREC and defines the similarity of the project under consideration to previously developed projects. FLEX stands for Development Flexibility, RESL for Architecture / Risk Resolution, TEAM for Team Cohesion, and PMAT for Process Maturity. Further information about the SF is found in [4] and [5]. Each SF can be rated qualitatively on a scale from Very Low to Extra High, and the corresponding quantitative value enters the equation, to define either economies of scale, or diseconomies of scale.

Scale Factor	Very Low	Low	Nominal	High	Very High	Extra High
PREC	6.20	4.96	3.72	2.48	1.24	0.00
FLEX	5.07	4.05	3.04	2.03	1.01	0.00
RESL	7.07	5.65	4.24	2.83	1.41	0.00
TEAM	5.48	4.38	3.29	2.19	1.10	0.00
PMAT	7.80	6.24	4.68	3.12	1.56	0.00

Table 2.1: COCOMO II Scale Factors

If all SF are rated Extra High, the variable  $E$  equals the constant  $B$ . In the case of a persistent voting of Very Low for each SF, the value 0.316 is added to the constant  $B$ .

The EM (Effort Multiplier) is the last variable to describe in equation 2.3. The early design and the post architecture phase differ in the number of effort multipliers used to estimate the cost. Seven are used in the early design phase and seventeen in the post architecture phase, considering the amount of available information in these two phases. These EM are the corresponding values of the rated cost drivers (CD), whereas the cost drivers define characteristics which affect the effort to conduct a software development project [4]. Table 2.2 shows the cost drivers and their corresponding EM.

CD	Extra Low	Very Low	Low	Nominal	High	Very High	Extra High
RCPX	0.49	0.60	0.83	1.00	1.33	1.91	2.72
RUSE			0.95	1.00	1.07	1.15	1.24
PDIF			0.87	1.00	1.29	1.81	2.61
PERS	2.12	1.62	1.26	1.00	0.83	0.63	0.50
PREX	1.59	1.33	1.12	1.00	0.87	0.74	0.62
FCIL	1.43	1.30	1.10	1.00	0.87	0.73	0.62
SCED		1.43	1.14	1.00	1.00	1.00	

Table 2.2: COCOMO II Early Design Effort Multipliers

An EM higher than 1.0 leads to more development effort, whereas an EM lower than 1.0 leads to less development effort. An empty cell means that the corresponding qualitative

rating is not available for the cost driver under consideration.

RCPX stands for Product Reliability and Complexity, RUSE for Developed for Reusability, PDIF for Platform Difficulty, PERS for Personnel Capability, PREX for Personnel Experience, FCIL for Facilities, and SCED for Required Development Schedule. Further information about the cost drivers and how to rate them is found in [4] and [5].

**Schedule Estimation** Estimated PM indicates the effort which has to be put into a project to successfully complete it. The variable TDEV (Time to Develop) can be calculated to determine the calendar time in months, needed for the elaboration and construction phase. COCOMO II uses the convention that 100 percent of the development effort is done in these two phases. Table 2.3 shows the Model-Based Architecting and Software Engineering (MBASE) phase and schedule distribution percentages, consistent with the Rational Unified Process (RUP) [25]. MBASE [6] is a software development process developed by Barry Boehm, used in COCOMO II for describing the percentaged phase distribution.

Phase	Effort in %	Schedule in %
Inception	6	12.5
Elaboration	24	37.5
Construction	76	62.5
Transition	12	12.5
Totals	118	125

Table 2.3: COCOMO II Phase Distribution Percentages

Besides the 100 percent development effort needed in the elaboration and construction phase, another six percent is needed to conduct the inception phase and another twelve percent is needed to conduct the transition phase, totalling 118 percent for the whole MBASE process spiral model [4].

TDEV is calculated following equation 2.5, where  $C$ ,  $D$ , and  $B$  are constants which can be calibrated, initially set to  $C = 3.67$ ,  $D = 0.28$  and  $B = 0.91$ .

$$TDEV = [C \cdot (PM)^{(D+0.2 \cdot (E-B))}] \cdot \frac{SCED\%}{100} \quad (2.5)$$

For the calculation of TDEV, PM is calculated excluding the EM SCED. SCED serves as an input to the TDEV equation, and describes the schedule compression / expansion percentage.  $E$  is calculated following equation 2.4, and describes the projects economies of scale.

Using the COCOMO II approach, one can estimate the likely cost of a software project

and the needed months to conduct a project. This estimating framework is used to create test data in chapter 7.1. An example using COCOMO II to estimate costs is presented, and can be used to foster understanding of the cost estimation equations presented above.

### 2.2.2 Software Project Risk Level Quantification

Beside the quantification of risks, and relating the risks to the potential return of a project, calculating the overall project risk level can be very useful for comparing projects. An approach to calculate the risk value in percent is presented here, and is used in [9] to evaluate software project portfolios, considering the particular risk levels of each project.

A questionnaire [10] which comprises 211 questions is used in this approach. These questions cover ten different risk groups, consequently referred to as risk factors, of software projects. These factors are, for example, analysis, design, test, team and organisational structure.

Each question can be answered with six different possibilities. The answers express the relevance of the question, and varies from 0 (not relevant for the project), and 1 (very low risk) to 5 (very high risk). After calculating and normalising the median of all answers concerning a risk factor, the calculated value is multiplied with the risk factor's weight, whereas the risk factors weight specifies the relative importance of a factor for the success or the failure of a software project [9]. Table 2.4 shows the results from a study, presented in [9], regarding the weights of the factors. Since these weights are critical for the significance of the approach, the weights should be adjusted to a company's environment, based on expert knowledge and historic information.

Factor	Small	Medium	Large
Analysis	12.36	12.57	10.78
Design	8.59	7.52	6.23
Coding	4.84	4.13	4.00
Tests	7.36	6.17	5.82
Planning	15.26	13.04	13.85
Control	10.39	11.64	12.19
Team	11.28	11.53	12.63
Contracts	3.40	5.37	4.60
Policies/Structure	11.41	12.47	14.11
Clients	15.11	15.57	15.79

Table 2.4: Weighted Risk Factors in Percent

The randomly created risk values for the projects in the test set, presented in chapter 7.1, can be created in a real business using this approach.

Besides Project Management, Program Management is a substantial part of PPM, and is presented consequently.

### 2.3 Program Management

Project management deals with conducting individual projects. To plan, carry out and coordinate multiple, interdependent projects, program management is utilised. The negative impact of no overall control and coordination between projects, as well as the efficiency deficit in loosely regulated staff assignment responsibility, lead to the demand for a management construct, distinct from project management [32]. This is an approach that overviews several projects, manage them in a coordinated way, with the focus on creating benefits, which could only be realised with the collaboration of several projects.

The term *program* is commonly referred to a group of interdependent projects, managed in a coordinated way. The main goal is to obtain control and benefits, which would not be achievable, if these projects were managed individually [38]. The management of programs is defined by the PMI in [38] as

"the centralised, coordinated management of a program to achieve the program's strategic benefits and objectives."

Program management covers three ample management themes. Benefits management deals with the identification of tangible and intangible benefits, interdependencies of benefits, their iterative realisation and the organisational impact of the program. Stakeholder management deals with individuals and organisations which have an interest in at least one of the programs' outcome. The impact of the outcome could be either positive or negative. It is in the responsibility of the program manager to ensure the effective integration and communication with all stakeholders. Program governance is the third management theme. This theme deals with the process to create and monitor policies, procedures and organisational structures associated with a program. Achieving program goals in an efficient and effective organisational environment, while addressing risk and stakeholder requirements is the specified result of this process [38].

Projects are grouped into programs by several reasons [38] listed below:

- Projects share a common attribute such as client, customer, seller, technology or resource
- Interdependencies of tasks

- Resource constraints amongst projects
- Activities to reduce risks which impact several projects
- Change in organisational direction which affect several projects, whereas the effects have to be coordinated in a centralised way

Program management provides project management with direction and guidance. In the program life-cycle, several projects are initiated and the effort of each project is bundled to attain program level benefits. Project interdependencies have to be identified, monitored and coordinated by the program manager [38]. It is of special importance to establish communication channels between project managers in interrelated projects.

At this point, the first goal for a PPM process is defined. All identified goals are listed in chapter 3.2.

---

### **Goal I**

A PPM process should support the portfolio manager in a way that projects are grouped into programs, based on the above noted reasons. The grouping should be understood as a proposal. Projects can be removed and added, as well as the grouping could be removed at all.

---

Processes covered in program management are classified into five groups. The *Initiating Process Group* authorises the program and creates a plan for benefits realisation. The *Planning Process Group* defines the actions to deliver the benefits and scope of the program. The *Executing Process Group* is in charge of carrying out the plan for the program and delivering the defined benefits. Identifying variances from the program management plan and the measurement of benefit realisation progress is part of the *Monitoring and Controlling Process Group*. Carrying out the closing of the program is the responsibility of the *Closing Process Group* [38].

Since an ideal PPM process aims to support the PPM decision makers in planning programs, parts of the *planning process group* are presented in the following paragraph.

Figure 2.3 shows the processes covered in the *planning process group* of program management. *Resource Planning*, *Cost Estimating and Budgeting* and *Risk Management Planning and Analysis* are presented below in order to provide the theoretical basis for the program-related part of the proposed PPM process.

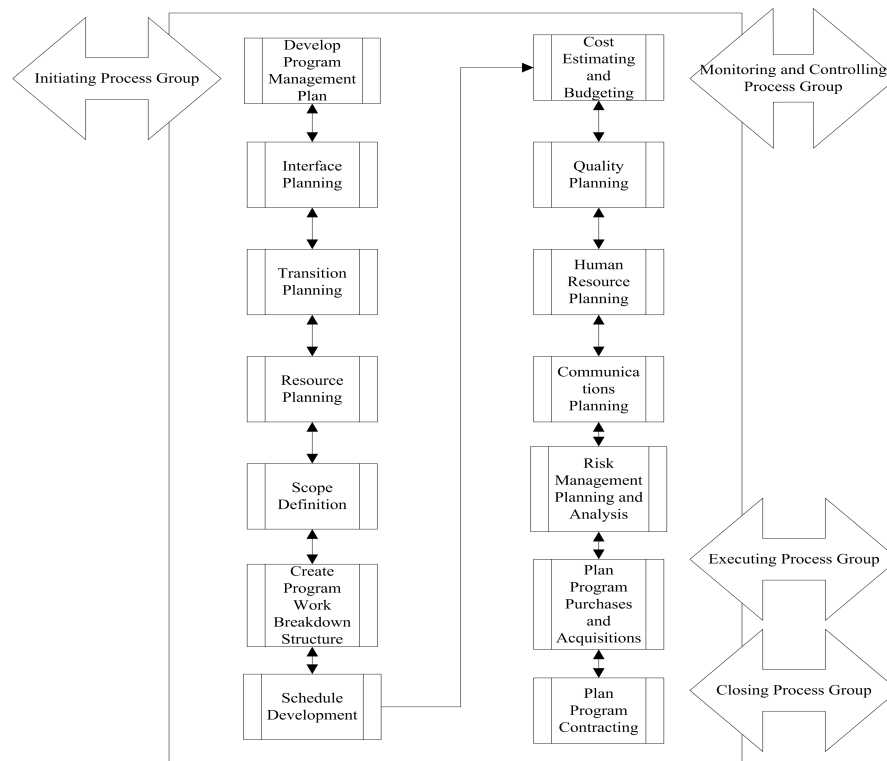


Figure 2.3: Planning Process Group; Source: [38]

**Resource Planning** Information about the resource pool, the program scope statement and the program work breakdown structure help the program manager to determine the people, equipment, materials and other resources needed, to conduct the activities of the program. The output of this process is a detailed description of the needed resource quantity, as well as a plan on how to use the resources effectively [38].

### Goal II

A PPM process should support the program resource planning process in a way that it delivers a bottom-up proposal for the needed resources. Bottom-Up means that the resources needed for all the projects in a program are accumulated.

**Cost Estimating and Budgeting** The aggregated costs for all program activity, including project and non-project activity, are transferred into an overall program estimate in the process of cost estimating. One approach is to sum up the individual estimates of the projects and work packages. The other one is to estimate the costs for the overall program [38].



### Goal III

A PPM process should support the program cost estimating process in a way that it accumulate the costs of each project contained in the program, based on the needed resources and corresponding unit rates.

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**Risk Management Planning and Analysis** This process comprises the identification of potential risks on program level, as well as on a project level. Based on the identified risks, a qualitative and quantitative risk analysis is conducted. Procedures and techniques to diminish the probability and negative effect of risks are documented in a risk response plan [38].

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### Goal IV

A PPM process should support the program risk management planning and analysis process in a way that risks, which have been identified on the project level, are presented for the program. This will support program managers in identifying inter -project risks, and will help to create response plans to risks that likely affect program benefits.

---

**A critical review** M. Lycett, A. Rassau and J. Danson argue in *Programme management: a critical review* [32] that current program management approaches strive to create an inappropriate degree of control over the projects. This may lead to excessive hierarchical bureaucracy and inflexibility. Furthermore, it is argued, that the creation of a supportive, open culture to enable knowledge transfer and collaboration instead of intense rivalry amongst the projects in a program would lead to effective cooperation and focus on the achievement of the overall program benefits. Another point of critique is the assumption in the standard program management literature, that there exist a *one-size-fits-all approach*. The authors argue that different types of projects would benefit from different program management approaches.

Main implication of this review is the major importance of strong relationships between project managers in a program, individual projects and the goals of the business, and between the program management and project management. Figure 2.4 illustrates these relationships, linked with the goals of program management, which could be reached through strengthened communication and improved relationships.

It is shown that improved project-to-project relationships could help to improve coor-

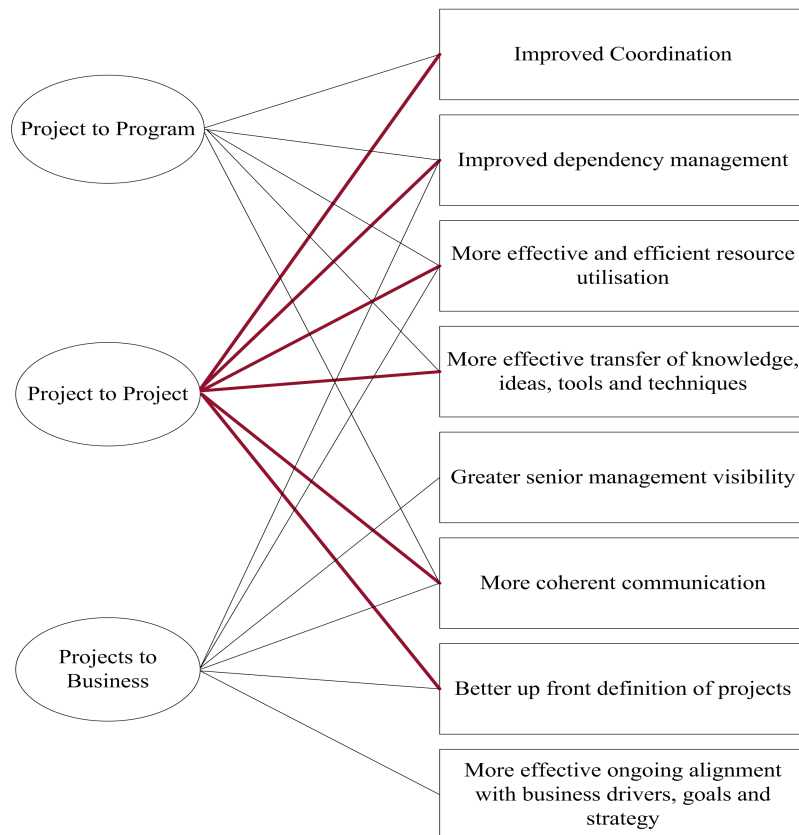


Figure 2.4: Key program management relationships and goals; Source: [32]

dination, improve dependency management, enhance resource utilisation and knowledge transfer. These relationships also have the potential to facilitate communication, and could lead to improved understanding of the project goals and scope.

Particularly interesting is the presented view on program management. According to the authors, program management should be perceived as contextual, variable and concurrent in praxis, and evolutionary in sophistication. Contextual means that a program structure should be built up, based on factors like interrelation of degree of projects, project-inherent characteristics and the nature of the organisation. Variable and concurrent in practice means that program management may operate on several levels. Evolutionary means that a program environment has to be build up sequentially and systematic. Also it means to accept the fact that more advanced features could be used only if appropriate program foundations exist already.

The senior management's realisation of the existence of various inter-project-relationship, is a first important step towards sophisticated program management.

## 2.4 Project Portfolio Management

The order of the sections about project-, program-, and portfolio-management illustrate the evolution of the management of projects. A detailed investigation of project management in section 2.1 illustrates the "birth" of this management topic more than fifty years ago. Since then, the importance of the structured management of projects grew steadily, and is today an indispensable part of each successful business. Project management is about doing projects right and attain project goals within time, scope, quality and budgeted costs.

The awareness that some ample business goals could only be reached by the coordinated management of multiple projects led to the creation of another management construct, called program management, presented in chapter 2.3. Improved communication, coordination, knowledge transfer and resource allocation between interdependent projects is the main focus of this management topic. By means of coordinating the outcomes of the programs' projects, an attempt is made to attain program level benefits.

The importance of project and program management is unquestioned, but both lack of asking one, maybe the most, important question, which is:

"Do we carry out the right projects?"

This question leads directly to the need of a structured process to present the answer. An answer which includes what "right" means for a specific organisation, how "right" projects could be differentiated from "wrong" projects. In short, a process with a fundament, built up around the following question:

"What's the use of running if you are on the wrong road?"

PPM is a management framework with the potential to provide answers to these questions and supports an organisation in choosing the "right" road. PPM is about selecting the projects for an organisation which best fit organisations' needs and strategic goals, with respect to available resources and budget. PPM is defined by the PMI as

"the centralised management of one or more portfolios, which includes identifying, prioritising, authorising, managing, and controlling projects, programs, and other related work, to achieve strategic business objectives [37]."

Harvey A. Levine presents a more process-oriented definition of PPM:

"PPM is a set of processes, supported by people and tools, to guide the enterprise in selecting the right projects and the right number of projects, and in

maintaining a portfolio of projects that will maximise the enterprise's strategic goals, efficient use of resources, stakeholder satisfaction, and the bottom line [31]."

As we can see, PPM is about choosing projects. A methodology to choose projects is especially important, because of the increasing number of potential projects in which to invest, and more complex project constraints, including budgets, personnel, risk, time and compliance. Furthermore, organisations face problems in balancing their portfolios, with regard to overall risk and a sane offset between long-, short and mid-term projects. Problems arise as well out of the lack of strategic alignment of the projects in a portfolio, projects which are chosen based on the power of a group of people and not on economic aspects, and varying methods to evaluate projects in the selection process [31].

The processes of PPM face up to this demanding circumstances. In practical terms, PPM is about defining goals and objectives, understanding and accepting trade-offs, minimising and diversifying risks, monitoring the portfolio performance and achieving a desired objective [31].

It is worth mentioning that PPM do not create a completely new organisational environment, with a significant number of new roles and departments. Rather it presents a way to establish communication between organisational parts which do not, or only in an inefficient way, interact with each other. A few new skills, methods, responsibilities, processes and tools, together with the top-level management's will to improve an organisation's performance, based on well established operation- and project management processes, could help an organisation considerably increases success.

The organisational parts which have poor interaction in an organisation without PPM processes are operations- and project management. Operations management deals with strategies, business performance, stockholder satisfaction, project selection, resource availability and income. Whereas project management is concerned with project cost, performance, stakeholder satisfaction, use of resources and use of cash [31]. PPM create processes to bring these two distinct parts of an organisation together, with the goal of gathering information from both parts and creating and distributing information not previously available to one or both organisational parts.

Figure 2.5 illustrates the above mentioned function of PPM and its central interconnecting responsibility.

PPM is more interwoven with the operational management than illustrated in this picture. Especially the parts *Strategic and Tactical Plans*, *Resource Availability*, *Budget and Cash Flow* and *Opportunity Management* are products of special operation management themes. The finance part of operation management provides PPM with tangible and accurate financial information, indispensable in selecting projects with respect to available

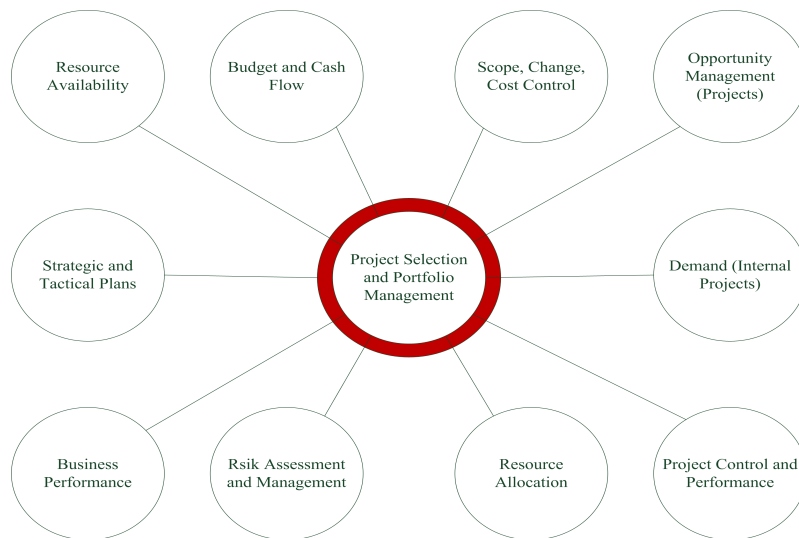


Figure 2.5: The interconnecting responsibility of PPM; Source: [31]

budget. Market opportunity and corresponding timeframes, legal obligations and operational requirements are produced by the marketing part of operation management and is a worthwhile input to strategic plans. Furthermore, human resource management provides detailed information about resources, skills and availability, and is therefore an essential input to selecting projects with respect to the available workforce [37].

Mature project management techniques are of special importance in PPM. This is due to the fact that a selection decision for or against a project are based on information gathered on the project level. Furthermore, PPM also measure the progress of the portfolio in attaining goals. Since the projects are the vehicle for moving towards the portfolio goals, this is done by gathering information from projects in progress, and their actual proportional contribution to the intended benefits. A portfolio comprises of all the prioritised and strategically aligned work of an organisation, including programs, projects and other work. The portfolio presents the projects which should provide certain benefits, in order to meet overall business objectives and strategic goals. The projects and programs in the portfolio are interconnected by sharing common goals and resources [37]. Figure 2.6 shows the relationships between the portfolio, programs and projects. It catches the readers eye that the overall portfolio contains other portfolios. The reason for this is that the root portfolio node is the overall portfolio. The portfolios at level two are portfolios for specific project types. These project types could be *Maintenance* or *Utility Projects*, *Growth* or *Enhancement Projects* and *Transformation Projects* [31]. This grouping is especially important because of the existence of various budgets for different project types and the fundamentally different characteristics of various project types. For example, a construction project has fundamentally different characteristics than an IT project, and

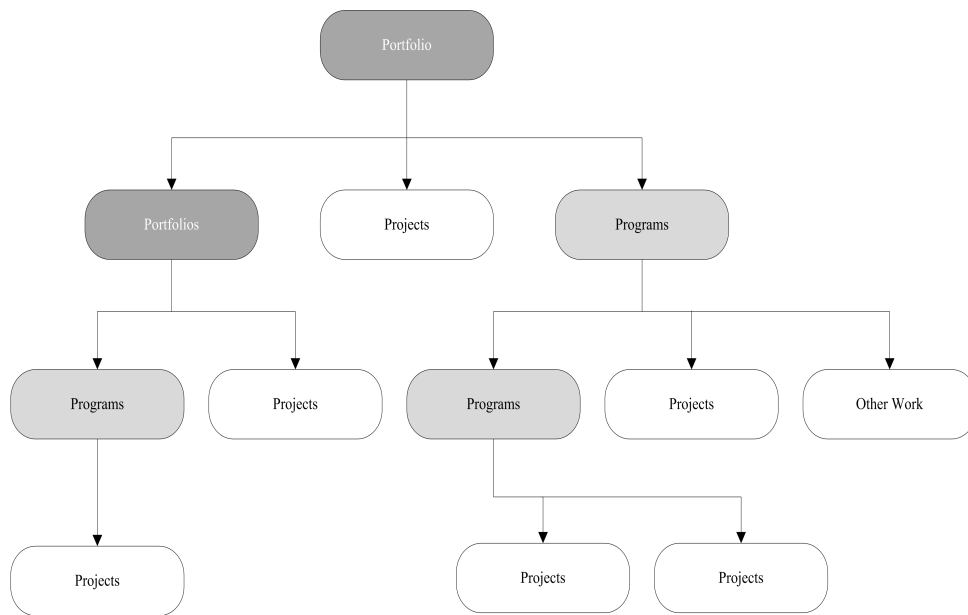


Figure 2.6: Possible Portfolio Relationships; Source: [37]

should therefore be evaluated and ranked in a separate portfolio.

After this introduction to the broad field of PPM, the next chapter presents processes for conducting PPM.

## 2.5 Project Portfolio Management Processes

In the year 1999, Archer presented the paper [1] "An integrated framework for project portfolio selection", including the groundwork for a stage-based portfolio creation process. The author presented valuable propositions which should be supported by a PPM process and the presented framework seem to have influenced today's [37] [31] project selection techniques and processes fundamentally. Figure 2.7 illustrates the framework. The idea of individual project analysis, together with a selection of the proposed projects, followed by the creation of an optimal portfolio, all aligned with the organisation's strategy, is found in each PPM process today, whereas today's processes show a more detailed dimension of PPM.

Let's begin with the most important step from the author's view. The aim of the *Optimal Portfolio Selection* step is to provide an optimal portfolio, while considering all project interdependencies. These interdependencies should include positive and negative project synergy, logical dependencies and resource rivalry. Archer proposed a two-phase approach, while the first phase creates a relative ranking of the projects, followed by op-

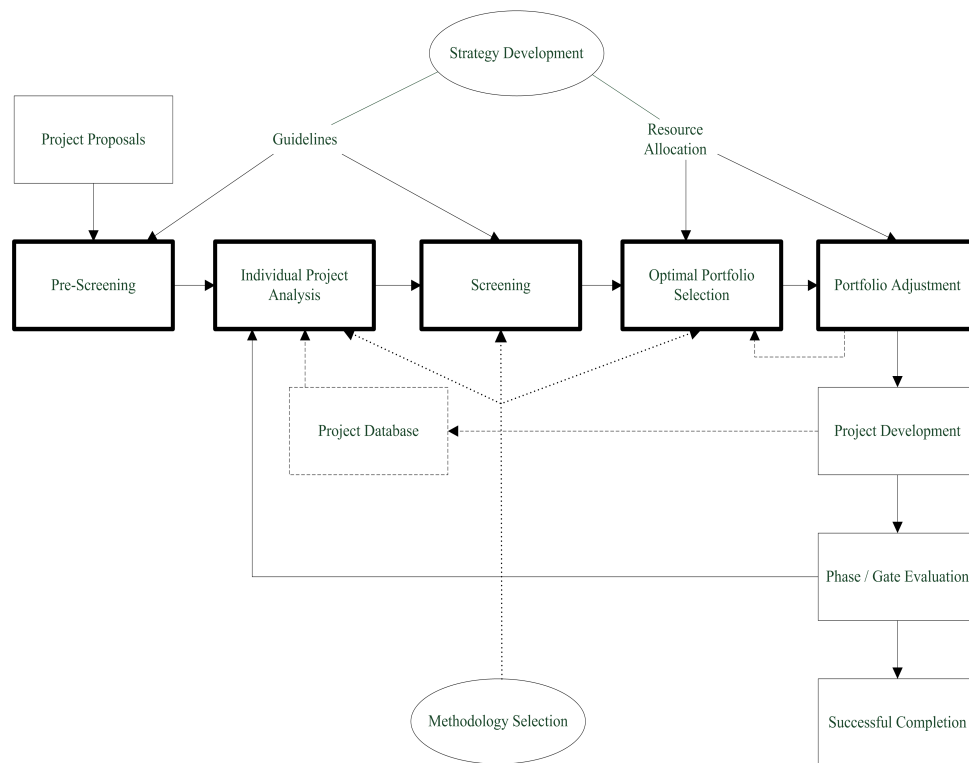


Figure 2.7: Archers Framework for Portfolio Selection; Source: [1]

timising the selection approach and the composition of the projects into a portfolio in the second phase. A relative ranking of the projects could be established by the Analytic Hierarchy Process (AHP). AHP is based on pairwise comparison of all possible combinations, and leads to a ranking based on the relative importance of the alternatives. Archer states that the relative ranking could be omitted if all project measures could be expressed quantitatively [1]. Being able to define all the relevant project characteristics in quantitative values, consequently applying an optimisation process on this values, is an explicit goal of the proposed PPM process.

Business leaders may have a strange feeling while thinking about a portfolio optimised by an algorithm, they don't know in detail. Therefore, it should be possible to define a "must-select" restriction for projects [31].

### Goal V

A PPM process should take into account provide methods and techniques to quantitatively measure all relevant project characteristics, in order to be able to apply an optimisation technique on the project selection process, without being forced to create a relative order of the proposed projects in advance.

---

### **Goal VI**

A PPM process should take the possibility that projects have to be conducted because of legal and economic circumstances, or the executives' will, into account. Therefore, it should be possible to select projects which definitely have to be included in each proposed portfolio.

---

The *Portfolio Adjustment* step defines that a PPM process has to enable the decision makers to manually adjust the proposed optimal portfolio, thus adding or removing projects from a portfolio, and adjusting budget boundaries or altering project schedules has to be possible. All relevant information has to be presented, and adjustments made to the portfolio should have an instant effect on the portfolios' key data (Net Present Value, Risk, time-to-complete, etc.) [1]. Combined with the "must-select" restriction, business leaders have full control over the portfolio.

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### **Goal VII**

A PPM process should provide functions and visualisation methods to present all relevant portfolio information. Changes made to the portfolio are either presented visually or quantitatively or both.

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*Screening* leads to the elimination of projects which do not meet predefined minimum criteria, regarding risk, uncertainty, or estimated rate of return [1]. The elimination of projects should be conducted with caution, because projects still in the project pool could be logically interrelated with the candidate to erase, or projects evolve their potential only in synergy with other projects.

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### **Goal VIII**

A PPM process should take logical relationships between projects into account.

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### **Goal IX**

A PPM process should take negative and positive synergy effects between projects into account, and adapt the worth of a portfolio in considering these synergy values.

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The missing process steps will be introduced briefly, because another, more detailed, process framework is presented below, and the ideas of the missing steps are included in the process steps of this framework. This framework is the basis for further investigation and presentation of PPM.

One of the not yet introduced process steps is *Individual project analysis*. This step is about calculating and estimating of a set of parameters for each project. *Pre-screening* ensures strategic fit of any project proposal. *Phase/Gate Evaluation* is about recurring evaluation of projects and the potential abandonment of a project [1], because of not meeting predefined goals or of change in scope. The idea of recurring project reviews is essential to PPM, providing a business with a process to abort inefficient projects, which are no longer aligned with the organisations strategy, or have the potential to provide a negative Return on Investment (ROI), and thus prevent the inefficient use of precious resources.

The PPM process, presented by Levine [31], is divided into two major processes. These are *Selecting Projects for the Pipeline* and *Maintaining the Project Pipeline*. This clear distinction is also part of the PPM process, presented by the PMI. The two distinct groups are called *Aligning Process Group* and *Monitoring & Controlling Process Group*. While their names are different, they have the same objective target. *Selecting Projects for the Pipeline* and *Aligning Process Group* deal with evaluating, selecting projects and balancing portfolios, considering strategic alignment, available resources and other arbitrary criteria. *Maintaining the Project Pipeline* and *Monitoring & Controlling Process Group* maintain the idea of periodical reviews, with the aim to monitor and evaluate projects in progress. If the evaluated projects do not still meet the predefined criteria, do not support the strategy of the business anymore or are subject to fail, this is the process that enables aborting them.

The PPM process of the PMI is taken as a reference here, because of its' detailed and clear structure. Figure 2.8 presents this PPM process, created by the PMI. The discrete steps and their knowledge areas are used to present the basic ideas behind these steps. Corresponding methods and techniques are provided in order to get a practical view of the steps. The methods and techniques presented will be used to compose the proposed PPM process, which consists of well-known PPM techniques, and an EA applied to the project selection problem.

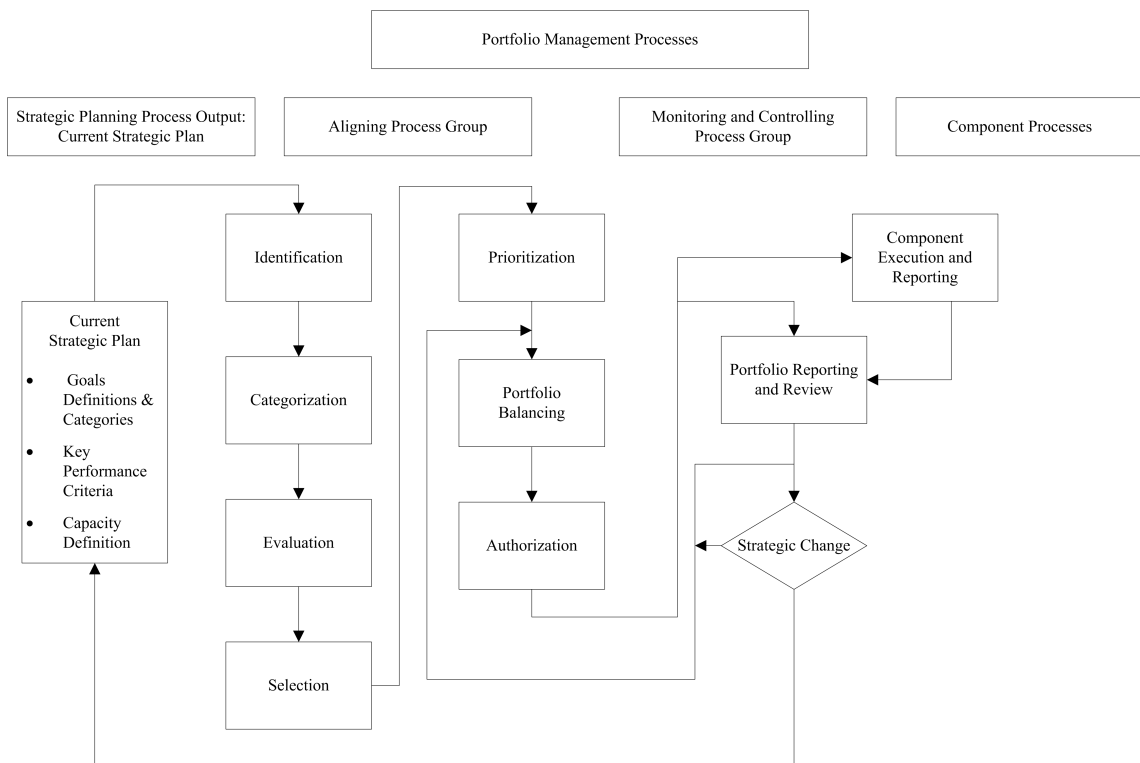


Figure 2.8: PMI PPM Process; Source: [37]

The subsequent paragraphs present the parts and knowledge areas of the PMI PPM process.

### 2.5.1 Strategy

The importance of strategic alignment of the projects an organisation conduct was mentioned already several times in the introduction of this chapter. This paragraph introduces the reader to the term "strategy" and its major importance for PPM.

A strategy in business is defined by B. Tregoe and J. Zimmermann as

"the framework that guides those choices that determine the nature and direction of an organisation."

This framework comprises the definition of a position of the organisation in the future. This position can be characterised by the organisation's wealth and size, customers, partners, products, technologies and geographical distribution. This aspired position is often referred to as the vision or mission of an organisation. This vision should be expressed in quantifiable goals. Ample approaches have to be defined to meet this goals. At the lowest planning level, projects or on-going activities have to support these approaches in order

to meet overall business goals. In a nutshell, a strategy is a set of approaches for attaining certain goals, whereas below each approach is referred to as one strategy [31].

The selection of projects is of major importance for a business, because the nature and direction of an organisation is defined by the conducted activities [18]. If the projects are not selected in consideration of the strategy, it is probable that the organisation is moving towards an unintended direction, overall goals are not attained and scarce resources are wasted.

A gap of tools to exactly measure in quantitative terms the alignment of projects to the strategy is identified in the literature [18]. To bridge this gap, a theoretical approach is presented, combining the need to identify variables in metrics on the portfolio level, which support the goals and strategies on the business level. Since it is probably very challenging to identify the correct variables and their exact effect, the approach is subject to further investigation, and the validity has to be tested thoroughly. A straight forward scoring model to calculate the Strategic Alignment Value SAV of a project will be presented in the paragraph *Evaluation*.

This approach uses numbers to quantify the impact of a project on each strategy. Although the numbers are quantitative and can be used in an optimisation process for project selection, the process is qualitative in nature, because the rating is based on expert knowledge and their intention.

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### **Goal X**

A PPM process should use the strategies, defined on the executive level, as input to the project evaluation and project selection process. An algorithm used to create efficient portfolios has to provide portfolios with a balance between the strategies, and should maximise the SAV of the portfolio.

---

The strategy plan provides the management of the portfolio not only with goals and approaches to attain this goals, but also with the direction to balance the portfolio. This direction is defined in terms of risk affinity, short-term versus long-term returns, available resources, key criteria, or in risk-to-benefit trade-off preferences [37].

---

### **Goal XI**

A PPM process should support preferences concerning the portfolio, defined in the strategy plan. These preferences are, for example, risk affinity, short-term versus long-term

returns, available resources, key criteria, and risk-to-benefit trade-off preferences.

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### 2.5.2 Identification

The *identification* step creates a list of new components, which have been proposed since the last project selection cycle. Based on information from the strategic plans like strategic direction and key criteria, projects which meet the predefined criteria are approved to move to the next step, or are declined if they don't meet it. For example, criteria could be in strategic alignment with at least one strategy, or an uncertainty not higher than a predefined level [37].

The following listing shows some possible key criteria [37]:

- Support of Strategic Objectives
- Quantitative benefits
  - Cost reduction
  - ROI
  - Net present value
  - Quality Improvement
- Qualitative benefits
  - Risk reduction
  - Legal requirements
- Resources required
- Project dependencies
- Key deliverables

The questionnaire for the component identification should be communicated and distributed throughout all departments, in order to reduce the number of proposed projects which do not meet the criteria [31].

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### Goal XII

A PPM process should support identification and pre-screening of components in a way

that projects which do not meet pre-defined criteria, are filtered and presented to the decision makers.

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### 2.5.3 Categorisation

The *Categorisation* step group projects which share a strategic goal and have the same measurement criteria, into categories. The following listing show some possible categories [37]:

- Increased profitability (revenue increase, cost reduction, etc.)
- Risk reduction
- Efficiency improvement
- Legal obligation
- Market share increase
- Process improvement
- Continuous improvement
- Business imperatives (IT compatibility or upgrades)

The categories are based on the strategic plan. Thus, the grouping into these categories is important concerning strategic alignment, and projects which cannot be related to one of these groups are subject to further investigation and possibly be rejected [37].

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#### Goal XIII

A PPM process should provide the possibility to group projects into categories. Furthermore the process should support creating balanced portfolios regarding the categories. The possibility to define preferences, for one or more categories, should be given.

---

### 2.5.4 Evaluation

The *Evaluation* step is tightly related to project scope-, time-, risk, and cost management, presented in the project management chapter 2.1. Mature project management planning and estimate processes are of special importance for the PPM evaluation step, because information from these project management techniques influence the rating of the project, thus being a crucial factor for the project's future.

The evaluation of projects is concerned with the strategic alignment, the possible return of the investment, cost resulting from a project over its lifetime, the resources the project requires, and exact project schedules, including resource and cost estimation for time-frames. Furthermore, risk and uncertainty should be investigated thoroughly and effect the rating of the project.

The next sections present these areas of project evaluation, combined with suitable techniques and methods.

**Strategic Alignment** Let's begin with the topic that gets so much attention in this thesis: The strategic alignment of projects. It is outlined in the preceding chapters that there is a need to align the projects of an organisation with the strategy of the organisation. Therefore, an approach, in fact a scoring model combined with the AHP, is presented to quantify the strategic alignment of a project. Although the numbers used to define the alignment of a project are obviously quantitative, the process is qualitative in nature, because the rating is based on expert knowledge and their intentions.

Strategy has been defined as a set of approaches to attaining certain goals on the business level. , Strategies which could be part of an overall strategic plan include decreasing running expenses, enhancing the diversity of the product range, increasing customer satisfaction, increasing IT reliability, and creating knowledge in IT security.

Most of the time, the strategies of an organisation do not have equal importance, that is to say, at least the stakeholders do not agree in the relative importance of the strategies. The relative importance could be determined in the process of creating the strategic plan. If a relative ranking of the strategies is missing, the AHP provide a method to attain one. The relative ranking is used to assign weighting to the strategies.

**Analytic Hierarchy Process** A relative ranking, created with the influence of all stakeholders, is especially important because of its direction-leading influence for the organisation. Making decisions is mostly combined with the realisation of trade-offs. To accept these trade-offs and create a common agreement on the outcomes, a structured methodology is essential.

The Analytic Hierarchy Process (AHP) is a structured methodology used for decision-making processes. This process is based on pairwise comparison of all possible combinations. The particular strengths are the possibility to reconstruct the decision making process, the combination of intuition and logic, and a facilitated way to harmonise the expectations of the stakeholders [40].

The first step in conducting the AHP is to structure the hierarchy of the problem. The hierarchy consists of the overall goal and derived sub-goals. These sub-goals can be further divided into criteria and sub-criteria. This breakdown has to be conducted under consideration of the maxim that criteria at a specific level, has to be comparable with criteria at the next higher level. Thus, we can say that the lower the level of the hierarchy, the higher the detail of the problem. A detailed view of the problem is often needed in order to judge the relative importance of sub-parts of the problem.

Each component at each level is subject to a process of prioritisation in order to create a relative ranking and weighting of the elements at the same level. The levels can be prioritised in an arbitrary order. After assigning the level-specific priority ranking, an overall ranking has to be established. To achieve this, the components at a sub-level will be proportionally distributed to their direct parent at the next higher level.

To make this clear, the process of prioritisation is presented below. The process of prioritisation utilises a reciprocal, pairwise comparison of all alternatives. Reciprocal means that the judgement, that component A is four times more important than component B, will lead to the reverse that B is one fourth as important as component A. Thus, the number of comparisons has to be  $N * (N - 1) / 2$ .

The judgements of the decision makers represent knowledge, feelings and intuition. AHP map the cognitive and emotional level, to the numerical level [40]. This mapping is conducted as shown in table 2.5.

The prioritisation and relative ranking is calculated by dividing the sum of each row through the sum of all values. The following equation shows this relationship, where  $rx$  is the row under consideration,  $c$  is the cell defined by  $rx$  and  $i$  or  $r$  and  $i$ ,  $n$  is the number of components which equal the number of cells respectively rows, and  $p$  is the prioritisation value for the row under consideration.

$$p_{rx} = \frac{\sum_{i=1}^n c_{rx,i}}{\sum_{r=1}^n \sum_{i=1}^n c_{r,i}} \quad (2.6)$$

Let's consider an example, the weighting of five strategies defined in the strategic plan, to make things clear. The five strategies that have to be ranked, are listed below:

- (S1) *decrease running expenses*

Definition	Numerical	Description
Equal Importance	1	Equal contribution to the compared components
Moderate Importance	3	One component is slightly favoured over the other one, based on experience and judgement
Strong Importance	5	One component is strongly favoured over the other one, based on experience and judgement
Very Strong Importance	7	One component is very strongly favoured over the other one
Extreme Importance	9	One component is favoured over the other one, in the highest possible order
Interim values	2,4,6,8	To judge components with in-between values

Table 2.5: AHP Judgement Scale; Source: [40]

- (S2) *enhance the diversity of the product range*
- (S3) *increase customer satisfaction*
- (S4) *increase IT reliability*
- (S5) *create knowledge in IT security*

In this straightforward example, we want to analyse the relative importance of these strategic goals, in regard to optimising the overall portfolio. Figure 2.9 shows the hierarchical relationship for this example.

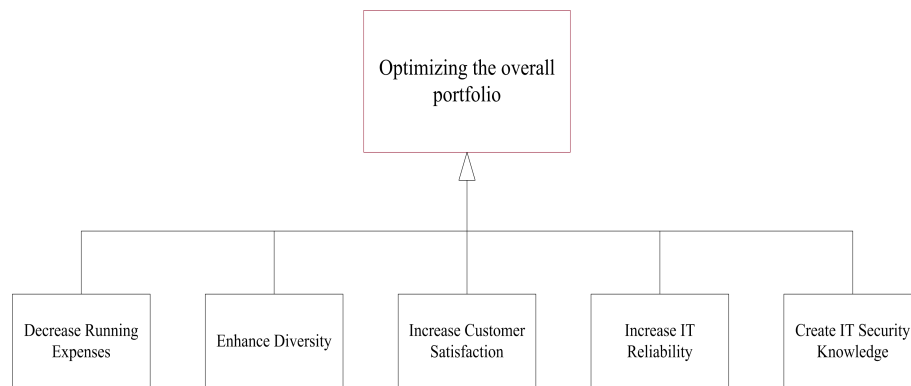


Figure 2.9: One Level Hierarchy

In the decision process, participants are asked the question of which one of the two alternatives is more important, with respect to optimising the overall portfolio of the organisation. The participants have to express their knowledge, feelings and intuition with



the expressions presented in table 2.5. The rating could lead to a discussion and consequently to a group decision, or the geometric or arithmetic mean of all decisions is calculated and considered as the group decision.

Table 2.6 shows the possible outcome of prioritising the five strategies. For example, the table present the information, that *increase the reliability of IT* is very strongly favoured in comparison to the *diversity enhancement of the product range*. After the pairwise comparison of the strategies, and the calculation of the priority values, by following the equation 2.6, the relative ranking is presented in the far right column.

Optimise Portfolio	S1	S2	S3	S4	S5	Prioritisation
S1	1	1/3	5	3	1/3	0.226
S2	3	1	1/3	1/7	1/3	0.113
S3	1/5	3	1	1/3	3	0.177
S4	1/3	7	3	1	1	0.289
S5	3	3	1/3	1	1	0.195

Table 2.6: AHP Strategy Prioritisation

The relative ranking can be easily calculated for a one-level hierarchy. If more hierarchies are part of the problem, and an overall ranking has to be created, the ranking of the sub-level has to re-calculated in consideration of the relative value of the parental component on the next higher level.

Figure 2.10 shows the strategy example with an added sub-hierarchy, and relative ranking calculated for each hierarchy. Figure 2.11 shows the same example with a calculated overall ranking. Because of its decomposition into more detailed sub- strategies, the strategy *decrease running expenses* is no longer part of the overall ranking, and therefore it is grey-coloured.

It is shown how a relative ranking of strategies could be created, with the help of AHP. The relative ranking, combined with a weighting of the strategies, can be created with other formal and informal techniques as well. This ranking is used in the proposed PPM process to evaluate projects in consideration of their strategic alignment. The method to conduct this evaluation, a scoring model, is presented below.

**Scoring Model with Weighted Strategies** In using the relative ranking of the strategies, with a method to score the alignment of a project to each of these strategies, a quantitative, measurable overall alignment value is created. The relative ranking assures that the alignment to a strategy is weighted, based on the preferences of the top-level management board. Thus, projects which align to a higher ranked strategy will obtain a higher overall

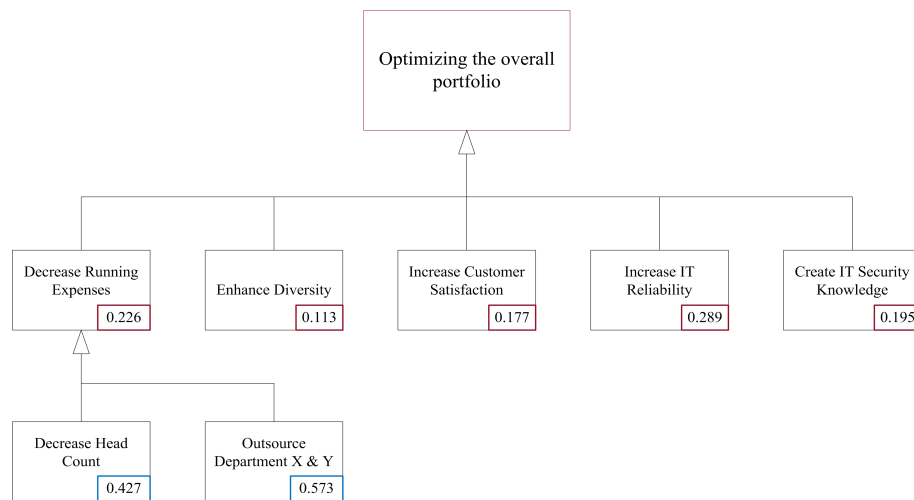


Figure 2.10: Two Level Hierarchy

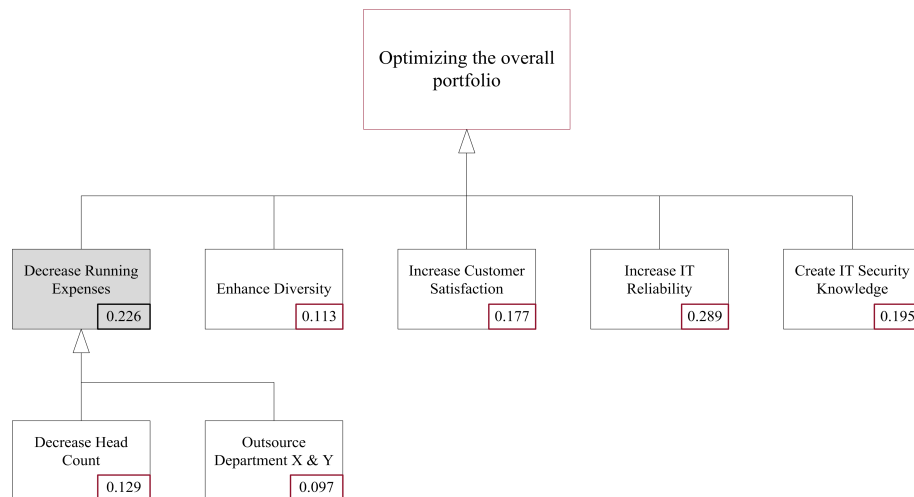


Figure 2.11: Global ranking

alignment value, and consequently have a greater chance of being part of the final portfolio.

**Goal XIV**

A PPM process should use the overall strategic alignment value in the optimisation algorithm to maximise the strategic alignment of the created portfolios.

Table 2.7 show such a scoring model, which is influenced by [37] and [31]. This exemplary strategy alignment project evaluation could be the data of a project, which

Strategy	Weight	Score	Total
increase IT reliability	0.289	9	2.60
decrease running expenses	0.226	3	0.68
create knowledge in IT security	0.195	0	0
increase customer satisfaction	0.177	3	0.53
enhance the diversity of the product range	0.113	0	0
<b>Total Score</b>			<b>3.81</b>

Table 2.7: Strategy Scoring Model

has the goal of exchanging the web servers of an organisation. A strong alignment was scored for the increase of IT reliability, a decrease of running expenses and an increase in customer satisfaction is likely, whereas the strategic goals *create knowledge in IT security* and *enhance the diversity of the product range* are not supported at all. This project would attain an overall score of 3.81, regarding strategic alignment.

Project stakeholders could try to improve the strategic alignment score by adding strategic value where there is not really any. To prevent this, it is important to communicate that the strategic alignment is important, but not the only characteristic to choose projects. Furthermore it is important to communicate the ranking of the strategies, thus communicating the preferences of the organisation. But there is no need to communicate the exact weighting, which could seduce stakeholders to align their project on paper to strategies with a higher weighting. Thus, the weighting column of the table 2.7 could be removed.

The score level has to be clearly defined, communicated and used consistently for the evaluation. Table 2.8 shows the score level used in this example and throughout in consequent examples.

Numerical	Description
9	Strong alignment and / or high impact
3	Moderate alignment and / or impact
1	Limited alignment and / or impact
0	No relationship

Table 2.8: Score Level; Source: [31]

This technique provides another important feature. The feature of grouping strategies. This grouping is especially interesting for strategies which were broken down into two hierarchies, as in figure 2.11. In grouping strategies, key indicators are created. These key indicators can be used to optimise a portfolio for a specific key indicator. For the two-level

hierarchy presented above, a grouping of the second hierarchy into a key indicator, *reduce cost*, would make sense. The key indicator value for a specific project is the percentage of the overall key indicator value.

By using such key indicators, a portfolio cannot only be optimised towards an overall strategic alignment, but also towards the optimisation of special key indicators.

**Revenue and Outcome** The project portfolio is in fact an investment portfolio. An organisation invests human resources, knowledge and money into a project, with the goal of attaining benefits from this investment. Like the shares for an investment portfolio, the potential projects for the project portfolio have to be evaluated in regard to their potential financial revenue. As in an investment portfolio, the ultimate goal is to maximise potential overall welfare, while adhering to constraints and risk preferences [31].

The financial metrics ROI and NPV are commonly used to analyse the potential financial performance of projects. The calculation of these metrics is part of the planning process in project management, and is presented in the chapter 2.1.4. An approach to measure potential revenue of IT projects under consideration of risk aspects is presented in the paper, "Integrative Ex-ante-Return-/Risk Estimation of IT Investments " [50].

The use of the NPV metric for portfolio selection is questioned because it treats short-term returns as more favourable than long-term returns. Furthermore, the nature of this metric prefers long-term investments to short-term investments [31]. This could lead to an asset of short-term projects in the project selection process, even if short-term projects are not favoured by the organisation.

While the selection of an appropriate financial metric is organisation-dependent, the maximisation of the overall portfolio is basically always the same. The optimisation process of PPM will always try to maximise the financial metrics which serve as an input to the selection process.

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### **Goal XV**

A PPM process should select projects for the portfolio, based on their financial characteristics, with the goal of maximising potential overall portfolio return.

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**Cost, Resources and the Time Factor** A project needs a certain amount of resources across its life cycle. Initial investments and various running costs, besides the cost of resources, have to be taken into account in the cost planning process of project manage-

ment. The processes for creating a budget are presented in 2.1.4. The output of the cost budgeting process is a budget plan for each phase of a project.

This budget plan should be used in the proposed PPM process to match the selected projects in the portfolio with the overall budget of an organisation, imposed by the strategic planning group for the overall, or a specific portfolio. Since the discounting of budget data to a net present value diminishes the richness of the information [41], the budget data should be investigated in the corresponding timeframe.

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### **Goal XVI**

A PPM process should impose constraints for valid portfolios in limiting the available budget per timeframe.

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The complexity to schedule all resources of an organisation across multiple projects is unquestioned [23]. A key objective of a balanced portfolio is the well planned use of the available workforce, strengths and skills [31]. The available workforce is bound to some restrictions, for example, staff with certain knowledge could not be hired arbitrarily, due to a potential lack of specialised workforce on the market. Nevertheless, there exists some tolerance in the available workforce. For example, a certain percentage of the workforce can be hired for projects based on contracts for the life-cycle of a project. To support the effective use of resources, and facilitate the schedule difficulty, a PPM process has to take the resource restrictions for portfolio planning into account.

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### **Goal XVII**

A PPM process should impose constraints for valid portfolios in limiting the available resources per timeframe.

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Ghasemzadeh et. al. use, in [16], an approach for project selection, where projects are considered as investments that can be started in an arbitrary timeframe, given that the project is finished before the planning horizon. It is of major importance to recognise that most projects cannot start in an arbitrary timeframe, but very often in a few distinct timeframes. It is also possible that a project can only start in one timeframe. For example, to meet a market opportunity. Each of this cases

- Start a project in an arbitrary timeframe

- Start a project in a few distinct timeframes
- Start a project in exactly one timeframe

has to be considered in the process of creating valid portfolio candidates. The restriction that projects have to be finished in the planning horizon will be adhered, because the budget and resource restrictions for timeframes not included in the planning horizon are not defined, and would therefore lead the whole planning concept ad absurdum.

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### **Goal XVIII**

A PPM process should provide the decision makers and project stakeholders with the possibility of defining the timeframes in which a project may start.

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**Risk and Uncertainty** Uncertainty is inherent to the process of project planning. A project is subject to external and internal influences. External influences are often beyond the direct control of the organisation (e.g. interest rate, resource shortage, natural disasters, ... ) [31], or internal influences like technical problems, illness of an employee with key skills, and delay of a delivery of another department. These influences could turn a promising project into a financial disaster. The project management knowledge area of risk management deals with uncertainty of projects. Identification and quantification of potential risks is necessary for mature project management, in order to identify possible ways to reduce risks and be prepared if a risk occurs.

But risk is not inherently bad. Long-term projects are often ranked as high-risk projects, because the longer the planning phase, the greater the uncertainty. But long-term projects are often very promising, because of their potential outcome. Furthermore, high risk projects often include high potential revenue. Thus, it is important to analyse and relate the potential revenue and the risks of a project. But it is also important to balance a portfolio to the stakeholders' predefined risk profiles, and not just exclude high-risk projects from the portfolio [37].

The project selection should be conducted in consideration of the risk of projects. A possibility is to make use of risk-adjusted revenue metrics, like risk-adjusted ROI and risk-adjusted NPV presented in [31]. Risk-adjusted revenue reflects the uncertainty of the project's outcome, and diminishes the probability that the project will be selected for the portfolio. A risk-based approach to evaluate the potential revenue of IT investments is presented in [50]. Another way is to select projects based on a few risk metrics (e.g. metrics regarding financial or schedule risks), or at an overall risk estimation value.

While the use of risk adjusted revenue metrics is the responsibility of the project management, a portfolio risk balance and alignment with the predefined risk profile should be carried out by the PPM. The use of both risk-adjusted revenue metrics, and balancing portfolio regarding risk affinity, is highly recommended.

---

### **Goal XIX**

A PPM process optimises the overall portfolio risk towards the predefined risk preferences of an organisation. Optimisation should be possible for one overall project risk metric, or for a few aggregated risk metrics, concerning, for example, financial, resource or schedule risks.

---

### **2.5.5 Selection, Prioritisation and Balancing**

The steps *Selection*, *Prioritisation* and *Balancing* have the goal of selecting the projects which will be part of the portfolio. This is done by creating a short list of the proposed projects which meet the predefined criteria. This short list is used to prioritise the projects for each criteria. Based on this relative ranking, a balanced portfolio with the greatest potential benefit, with regard to strategic alignment and various restrictions, is created [37].

The proposed PPM process combines these three steps in one step, which is called "create efficient portfolios". While the PMI approach focuses on selecting and ranking the projects, the proposed approach focuses on selecting the most promising portfolio from a set of created portfolios, using a mathematical optimisation approach.

The missing steps of the PMI PPM process, *Authorisation*, *Component Execution and Reporting*, *Portfolio Reporting and Review*, and *Strategic Change*, are presented briefly, because of their non-relevance for this thesis. This thesis has the goal of presenting a PPM process which facilitates the process of creating and selecting portfolios. The consideration of maintaining a portfolio would be interesting for further research.

*Authorisation* is a formal step to allocating all the needed resources to a project. The *Portfolio Reporting and Review* step uses data from the *Component Execution and Reporting* step, in order to regularly conduct portfolio reviews to assure strategic alignment, efficient resource allocation and to check project performance. The *Strategic Change* step is the process of adjusting the portfolio to major strategic changes made at the executive level [37].

At this point in the thesis, the reader knows the relationship between project-, program- and portfolio management. The processes of portfolio management have been introduced and methods and goals to conduct these processes have been presented. The research in this thesis is based on the goals found in the corresponding literature, and summarised in section 3.2.

The following three sections about related work dip into important topics for the presented thesis, which do present detailed information about mathematically based portfolio optimisation, evolutionary algorithms, and the visualisation of multi-dimensional data.

## 2.6 Mathematically based portfolio optimisation

Various approaches have already proven the applicability of meta-heuristics for the project selection problem. Some of the most promising are presented below.

In the year 2000, Ghasemzadeh and Archer [16] presented a decision support system, which follow the process steps of Archer's integrated framework for PPM [1], and combine them with a formal model, considering various variables and constraints. The possibility to making manual adjustments is given through adding or removing projects. A very interesting contribution is the consideration that projects can start in an arbitrary timeframe, given that the project is completed within the planning horizon.

In 2003, Stummer and Heidenberger presented a three-phase approach [42] for PPM in the field of research and development. With the use of an Integer Linear Programming Model, they provided a process to deal with non-numerically restricted project interdependencies, Logical & Strategic constraints as well as Resource & Benefit constraints. One of the main contributions is the examination of resources and project expenditures in their corresponding timeframes. In comparison to the discounting of project attributes to a certain point in time, timeframes deliver a more accurate image of the business environment [42]. Disadvantages of this approach compromise its inability to deal with incomplete data sets, and the process or time-related restriction on approximately thirty projects [42].

In 2004, Doerner and Gutjahr published a so-called *Pareto Ant Colony Optimization Approach* [14]. Artificial ants construct valid project portfolios and take into account complex project interactions. The consideration of project synergy, the good results it has shown in experiments and the possibility of easily adding heuristic information to the



algorithm makes it a valuable approach [14].

In 2005, Medaglia, Graves and Ringuest presented an evolutionary approach for project selection [33]. They utilised a genetic algorithm, combined with random parameter values to model project selection under uncertainty. To model uncertainty is of specific relevance, because it is difficult in the project selection stage to define parameter values exactly, due to various internal and external influences (risk, political issues, interest rates, economic changes, and so on). Uncertainty could be modelled as specific random values following triangular, exponential, and Erlang distributions like in [33], or with the use of likely values as proposed in [1].

Each of the above presented approaches add valuable information and knowledge to the topic of creating optimised project portfolios. The approaches are analysed and inspired the author in creating an evolutionary approach to the project selection problem. Some ideas of these works are used in the presented approach, and expanded with new methods. Section 3.2 and 3.3 does describe the research issues regarding the mathematically based optimisation, using an evolutionary algorithm.

The topic of evolutionary algorithms is presented below, introducing the reader into this concept, and presenting the evolutionary algorithm mPOEMS.

## 2.7 Evolutionary Algorithms

Crossover, mutation, and evolution of a population are the basic principles of evolution and natural selection. Evolutionary algorithms (EA) imitate nature's behaviour, and adapt the basic principles to evolve a set of solutions towards the optimum solution of a problem. EAs are search and optimisation algorithms, especially suitable to solve multi-objective optimisation problems [11]. Basic working principle is the combination of promising parents to create, hopefully better, offspring. Quality criteria are used to measure and compare solutions, and consequently converge the set of solutions towards the optimal or near-optimal frontier [34].

In comparison to single-objective algorithms, multi-objective optimisation algorithms are especially suitable to find and create multiple optimal solutions. Multi-objective optimisation is characterised by the fact that there usually does not exist one optimal solution, given the absence of any high-level information concerning the preference of certain objectives [11]. Instead, multi-objective optimisation is characterised by the existence of multiple optimal solutions, where a solution cannot be optimal in each, often conflicting,

criterion. Thus the nature of multiple objectives, is accompanied by the realisation of existing trade-offs between the objectives.

The concept of the pareto-optimal front deals with the optimal solutions, taking into account the trade-offs between the objectives. Solutions on the pareto-optimal front are considered as superior to all other solutions, given that all objectives are taken into account [52]. To understand the concept of superiority, one has to understand the concept of dominance. The concept of dominance states that one solution  $x$  dominates another solution  $y$ , if the following conditions are true [11]:

1. Solution  $x$  is no worse than solution  $y$  in all objectives
2. Solution  $x$  is better than solution  $y$  in at least one objective

If these conditions are fulfilled, solution  $y$  is assumed to be dominated by solution  $x$ , and superiority of solution  $x$  over solution  $y$  is given. The pareto-optimal front is a set of non-dominated solutions. Non-domination between two solutions is given, if none of both solutions is better in consideration of all objectives. For the sake of clarity, let's consider an optimising problem with two objectives to minimise, to compare solution  $x$  and solution  $y$ .

	Objective One	Objective Two
Solution $x$	0.33	2.67
Solution $y$	0.76	1.56

Table 2.9: Non-Dominance

It is easy to see that solution  $x$  is better than solution  $y$  in objective one, and solution  $y$  is better than solution  $x$  in objective two. Hence, condition one of the dominance concept is violated, none of the two solutions is better than the other with respect to both objectives, and therefore these solutions are non-dominated with respect to each other.

In addition to the definition that the pareto-optimal front is a set of non-dominated solutions, the pareto-optimal front adheres to the condition, that any solution not part of the pareto-optimal front, is dominated by at least one member of the pareto-optimal front [11].

In figure 2.12, the pareto optimal front of the knapsack problem for 500 items and two knapsacks, used for the comparative study of EAs in [52], is plotted. The data for the pareto-optimal front and the test problem suite, can be found in [53]. Creating solutions as close as possible to the pareto optimal front, is a designated goal of any multi-objective optimising algorithm. The second goal is to find a set of solutions as diverse as possible

[11]. To attain diversity is of special importance, in order to cope with the trade-off nature of multi-objective optimisation. A diverse set of solutions enhances the possibility that a solution will meet the trade-off preference from a decision maker.

A solution that is not part of the pareto optimal front is dominated by at least one member of the pareto optimal front. Therefore, the solution space is divided into two areas, the dominated and the non-dominated area. Pareto optimality is often not attained by EAs. Instead the goal is to create solutions as close as possible to the pareto optimal front. Nevertheless, the created solutions are also divided into a dominated area, and a non-dominated area. The non-dominated solutions are particularly interesting, because they are the best solutions found, often referred to as the efficient frontier.

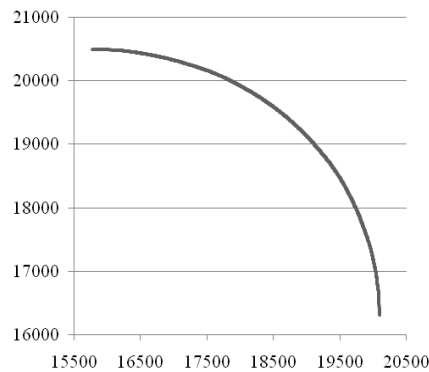


Figure 2.12: Pareto Optimal Front

SPEA (Strength Pareto Evolutionary Algorithm) [51], SPEA-2 [54], NSGA-2 (Non-dominated Sorting Genetic Algorithm) [12] are some of the most promising EAs already published. Each implementation of an EA is based on basically the same structure. So-called chromosomes are used to represent the problem structure. Most often, a chromosome encodes a complete solution to the problem under consideration [26]. Evolutionary generation is used to evolve the set of chromosomes, and a fitness value is assigned to select the best chromosomes of each run. Assignment of the fitness value is conducted by taking into account the problem objectives under consideration. Crossover and mutation of the chromosomes are the common operations, used in the evolutionary generation of new offspring.

Recently, mPOEMS (Multiobjective Prototype Optimization with Evolved Improvement Steps) was introduced [27]. mPOEMS is an EA, embedded into an iterative optimisation framework, with at least one fundamental difference to the above-mentioned EAs.

### 2.7.1 mPOEMS

Instead of encoding a complete solution of the problem under consideration in a chromosome, mPOEMS encodes modifications of a solution in a chromosome. These modifications are called actions. Each action modifies a selected prototype in a certain way, whereas the actions are problem-dependent, and will be designed especially for the problem at hand. Regarding the knapsack problem, an action, which would invert the value of a randomly chosen item in the solution vector, would be suitable. Besides the definition of actions which truly modify a solution, so-called *nop* (no operation) actions are defined. These *nop* actions have no effect on a solution, and are used to implement a variable length of the chromosomes [27].

Chromosomes are evolved in each EA mentioned to create solutions as near as possible to the pareto optimal front. Since mPOEMS encode modifications, which hopefully improve the prototype, in chromosomes, the multi-objective EA (MOEA) used in mPOEMS evolves sets of action sequences. Figure 2.13 shows the iterative optimisation framework in which the MOEA is embedded. In the first step, a base of randomly generated solutions is created. Consequently, a prototype is chosen from the non-dominated set of the solution base. The prototype and the solution base serve as input to the MOEA, which in turn output the final population of evolved action sequences. Figure 2.14 outlines the working principle of the utilised MOEA, explained in detail later. New solutions are created by applying the final population of action sequences to the prototype. The last step of an iteration does merge the solution base with the newly created solutions. This is done by replacing the worst solutions of the current solution base, with the best solutions of the newly created ones. Therefore, the solutions in the solution base are getting better in quality, while remaining constant the quantity of solutions in the base [27].

```

1   generate(SolutionBase)
2   repeat
3     Prototype ← choosePrototype(SolutionBase)
4     ActionSequences ← runMOEA(Prototype,SolutionBase)
5     NewSolutions ← applyTo(ActionSequences,Prototype)
6     SolutionBase ← merge(NewSolutions,SolutionBase)
7   until(iteration number equals configuration value nIterations)
8   return SolutionBase

```

Figure 2.13: Outline of the mPOEMS algorithm

The first step in the MOEA generates a population of action sequences, referred to as *OldPop*, which are consequently evaluated in the second step. The evaluation is conducted by applying the created action sequences to the prototype, and temporarily merg-

```

1  generate(OldPop)
2  evaluate(OldPop)
3  repeat
4      NewPop ← evolutionaryCycle(OldPop)
5      evaluate(NewPop)
6      OldPop ← merge(OldPop,NewPop)
7  until(iteration number equals configuration value  $nGenerations$ )
8  return OldPop

```

Figure 2.14: Outline of the MOEA used in mPOEMS

ing these created solutions with the solution base into a set  $S$ . Based on the domination concept, the solutions in the  $S$  set are assigned a fitness value. The attained fitness value for the solutions in the temporary set  $S$ , is, in turn, assigned to the corresponding action sequences which have been used to create the evaluated solutions. Thus, the newly created action sequences are evaluated in relation to the solutions, already in the solution base. In a few iterations, restricted by the variable,  $N_{Generations}$ , offspring of the created action sequences is created in the evolutionary cycle, which are, in turn, evaluated, and consequently merged with the so-called old population of action sequences. The final population of action sequences is returned to the iterative framework, and applied to the prototype, in order to create new and better solutions.

A first evaluation of mPOEMS, presented in [27], show very promising results regarding quality, diversity of the solution set, and behaviour regarding great problem instances. The fact that mPOEMS found the front closest to the pareto optimal front in this evaluation, its general applicability to multi-objective problems, the diversity of the non-dominated solutions it creates, and the simplicity to adapt the algorithm to new problem instances, makes mPOEMS the ideal candidate to be applied to the project selection problem in PPM.

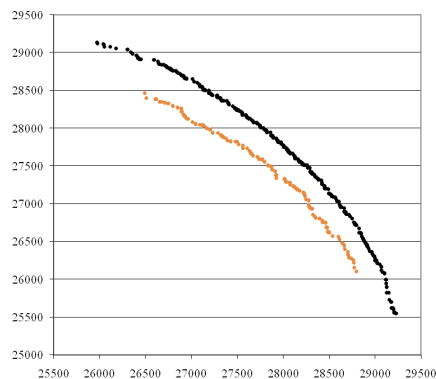


Figure 2.15: Two Knapsacks, 750 Items

Figure 2.15 shows the pareto optimal front for the knapsack problem with 750 items in black, and the dots in orange represent the solutions found by *mPOEMS in JAVA* [24] after 100 iterations, and about 150,000 sampled solutions.

Since portfolio data, and especially the pareto-optimal front that contains numerous portfolios, is a highly multi-dimensional data set, sophisticated visualisation and data exploration techniques have to be used to be able to present all needed information clearly, and gain insight. This thesis will present a group decision process which visualises the portfolio data. Therefore the topic *Visualisation of multi-dimensional data*, is part of the related work, and is presented consequently.

## 2.8 Visualisation of multi-dimensional data

The human three-dimensional perception requires sophisticated visualisation techniques, to clearly present information which has more than three dimensions. Standard techniques like X-Y plots and bar charts are limited in the number of dimensions they can visualise clearly. Because of the growing complexity of data, and the potential of sophisticated visualisation techniques to provide insight into this data, the field of information visualisation was getting more and more attention in the last decade.

Various techniques to visualise multi-dimensional data have been presented. Among them are Parallel Coordinates [20], Treemaps [43] and Stardiates [30] [29].

Parallel Coordinates are able to visualise multi-dimensional data in a two-dimensional method. This method creates, for a data tuple of the size  $n$ , a visualisation with  $n$  parallel y-axis, whereas each y-axis may have its own range of values. For each data tuple, a data point is created on the corresponding y-axis, consequently connected with each other, resulting in one line for one data tuple [45]. Figure 2.16 shows the parallel coordinates for a car data set. Visualisation was created with the free parallel coordinates tool *Parvis*, which can be downloaded from the website <http://home.subnet.at/flo/mv/parvis/>.

Treemaps are especially suitable to visualise hierarchical data. They map tree-structured data to planar space-filling maps [43]. Rectangles are used to visualise the branches of the tree, whereas each branch is tiled into smaller rectangles, representing the sub-branches. Treemaps often allow the user to virtually explore the underlying data, whereas a click on a branch rectangle, leads to the visualisation of the data of the corresponding branch. Figure 2.17 shows the basic structure of an exemplary treemap with five branches. Each rectangle is a sub-branch, and the rectangles in colour are the leafs.

Stardiates create unique patterns of n-dimensional data. This is done by creating an axis for each dimension of the data, and arrange these axes in a circle [30]. The advantage

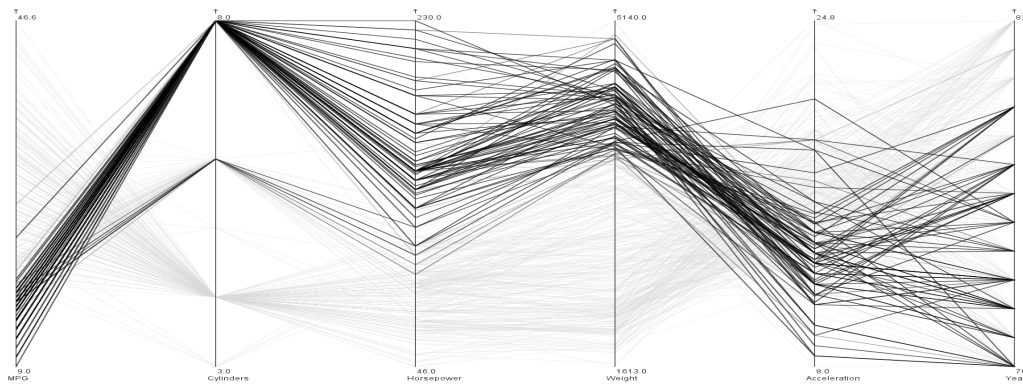


Figure 2.16: Parallel Coordinates showing a car data set

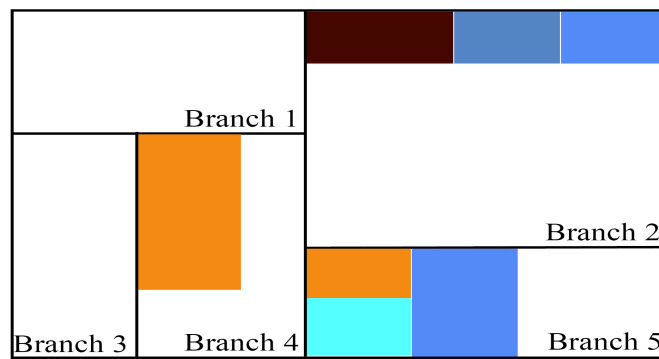


Figure 2.17: Treemap with five branches

of stardinates is their ability to visualise highly complex data, because for each dimension, one axis can be created. The disadvantage of this visualisation method is the restriction of the range of values, which can be visualised, since very high numbers of values lead to stardinates which lack expressiveness [30]. Figure 2.18 shows an exemplary stardinate with five dimensions and two data sets.

This chapter presented all related work for this thesis. Based on this related work, research issues have been identified, and are presented in the next chapter.

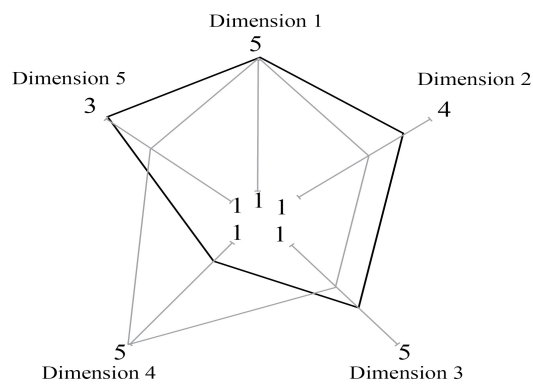


Figure 2.18: Stardinate with five dimensions



## 3 Research Issues

This chapter presents the main research issues of this thesis. Results, open questions and points of discussion regarding the research questions are presented in chapter 10. A short introduction into the theory of decisions serves as an entry point into this chapter, and as the justification to use the CIDECS framework as a guideline to model and present a project portfolio decision support system.

The theory of decisions is divided into two major research directions. Descriptive decision theory deals with empirical validated hypothesis how decisions are made, and the normative decision theory deals with the creation of decision models to guide and assist decision makers through a decision process, in order to make rational and traceable decisions [28]. The entire consequently presented theory is part of the normative decision theory, presented in [28].

Decision problems are common in various scientific fields, and are part of daily business. The decision theory focuses on problems with more than one, often conflicting goals. Thus, decision theory has close bonds with multi-objective optimisation. In fact, mathematical multi-objective optimisation is a research direction in the decision theory, located in the field of mathematical decision models. A number of mutually exclusive alternatives from which one has to be chosen, is characteristic for decision problems, whereas the number of alternatives is restricted by various constraints and restrictions.

The process of making a decision is separated into the following five steps: Firstly, the problem has to be formulated, secondly, the goal model has to be defined, thirdly, the feasible alternatives have to be generated, fourthly, one alternative has to be chosen, and fifthly, the alternative has to be realised. CIDECS, presented in the next chapter, 3.1, follows these five steps. Furthermore, the CIDECS framework fills and expands the theory with practical advice about how to conduct these steps. The fact that CIDECS is built on the theory of decisions leads the author to the conclusion that this guideline could be useful in creating the proposed decision support system. The usefulness of CIDECS to model such a complex decision problem is subject of research issue one.

## 3.1 Collaborative Interactive Decision Support

This section presents the CIDECS framework. Each step of CIDECS is presented in detail, and the research issue regarding CIDECS is defined.

### 3.1.1 Research Issue One: Feasibility of the CIDECS Process

---

Is the CIDECS framework useful to model complex decision problems?

---

It is investigated how the Collaborative Interactive Decision Support (CIDECS) framework can support decision makers to model and solve complex problems. The procedure of modelling and solving the project selection problem is taken as an example to test the usefulness of CIDECS.

The CIDECS framework is especially designed for interdisciplinary decision problems, covering the field of economics, collaboration engineering, software engineering project management, and quality management. Budget allocation optimisation problems, conducted in a group setting, are in the main focus of the framework. This thesis is based on CIDECS, and follows the CIDECS steps to create a decision support system for PPM, especially focused on the creation and selection of optimised portfolios.

This section presents the CIDECS framework, and links each step of the framework with at least one chapter of this thesis. Thus, an overview of the thesis is given, whereas each chapter can be related to a step of CIDECS.

The research threads of CIDECS cover the following four fields [3]:

- Modelling decision problems
- Methods and tools concerning stakeholder preferences, and cost/benefit models
- Methods and tools for knowledge management concerning repeated decisions
- Support of collaboration engineering in settings with multiple stakeholders (e.g. moderated workshops)

CIDECS deals with challenges like the fit of the decision model with reality, the trust in these models, alternative data reduction and visualisation of complex alternatives. To face

these challenges, CIDECS provides a set of process steps to model complex, important and repeatable decisions.

Because of its objective target and the focus on complex decision problems, CIDECS is chosen to be utilised as a guideline for this thesis. Each chapter of the main part of this document can be connected to at least one of CIDECS process steps. The following listing includes all of the CIDECS process steps.

- Step 1 - Decision model definition
- Step 2 - Utility model Cost-benefit definition
- Step 3 - Alternative generation
- Step 4 - Alternative reduction
- Step 5 - Interactive Visualisation & Discussion
- Step 6 - Decision Finalisation & Report
- Step 7 - Follow-up Result monitoring

These seven CIDECS steps are arranged as illustrated in figure 3.1.

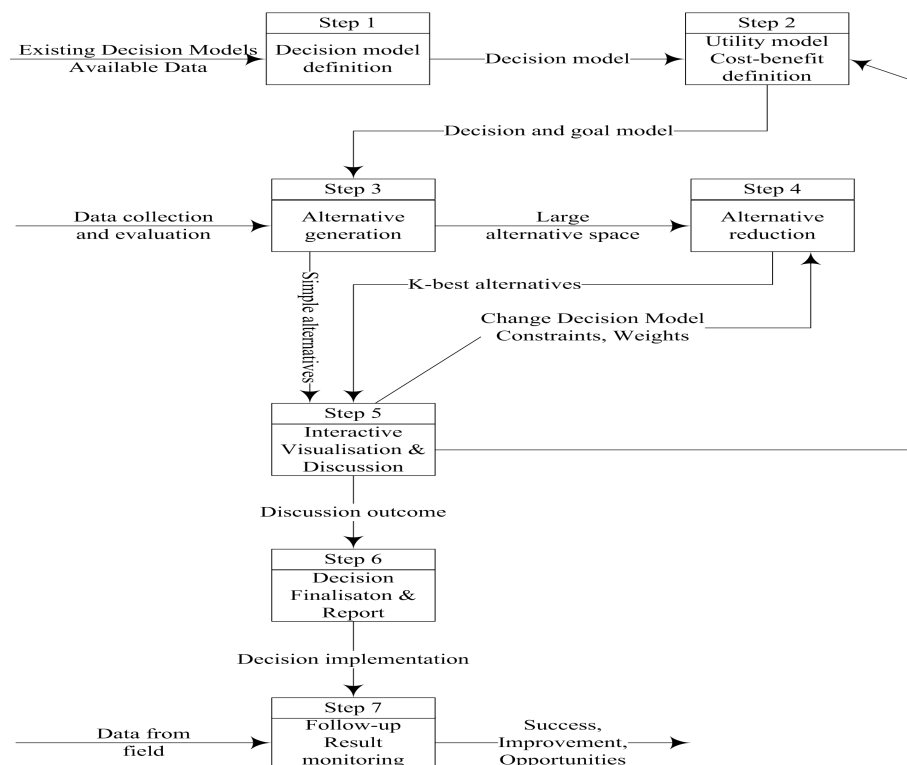


Figure 3.1: Collaborative Interactive Decision Support

*Decision model definition* is the first process step and deals with creating and defining a preferably realistic model of the problem environment. This includes a definition of the problem structure, available goals and potential constraints. Existing decision models and available data concerning the problem area serve as input data to this step. The decision model is the input for the step *Utility model Cost-benefit definition*. In this step, stakeholders define performance measures that can be considered in monetary or other arbitrary units. If there is a set of multiple criteria, criteria should be weighted and a subset of these criteria should be chosen.

In the steps *Alternative Generation* and *Alternative reduction*, solutions are created and if there is a large alternative solution space, the solutions found are reduced in the number of alternatives. This could be done through mathematical optimisation or other adequate heuristics. The *Interactive Visualisation & Discussion* step is provided by the framework to select one alternative out of the generated and reduced set of alternatives. Part of this step is a discussion about the alternatives, interaction concerning utility weights and sensitivity analysis, as well as relaxation of constraints to look for additional alternatives. This discussion should be logical and visually supported. In the *Decision Finalisation & Report* step, the final decision and key decision process steps are documented. The final step *Follow-Up Result monitoring* will monitor the outcome from decision realisation as feedback for improvement for further decisions.

The structure of this thesis is based on the CIDECS process, and each chapter can be related to at least one CIDECS step. The relation of the CIDECS steps to the thesis chapters is presented in detail in the approach section in chapter 4.

## 3.2 General Goals of Portfolio Optimisation

This section shows general goals of PPM, followed by the presentation of three research issues. The portfolio optimisation goals, identified in the investigation of the related work in chapter 2, are presented in table 3.1 in order to provide an overview of the goals for a PPM process, which focus on the optimisation of portfolios.

The following research issues are based on the goals listed in table 3.1.

Goal Number	Level	Summary
I	Program	Group projects into programs
II	Program	Bottom-Up proposal for the needed resources
III	Program	Cumulate costs of each project
IV	Program	Cumulate risk of each project
V	Portfolio	Quantitative measure all relevant project characteristics
VI	Portfolio	Provide logic to support "must vote" restrictions
VII	Portfolio	Present all relevant information quantitative or with graphs
VIII	Portfolio	Take logical relationships into account
IX	Portfolio	Take synergy effects into account
X	Portfolio	Balanced strategy alignment
XI	Portfolio	Take preferences (Risk, Return Time, etc.) into account
XII	Project	Support screening of projects
XIII	Portfolio	Categories and their importance for balancing
XIV	Portfolio	Maximise the overall strategic alignment value
XV	Portfolio	Maximise potential overall portfolio return
XVI	Portfolio	Limit the available budget per timeframe
XVII	Portfolio	Limit the available resources per timeframe
XVIII	Portfolio	Provide possibility to define starting timeframes
XIX	Portfolio	Optimise overall portfolio risk

Table 3.1: Goal Summary

### 3.2.1 Research Issue Two: Preparation of the Business Environment

Which steps does a portfolio manager have to conduct in order to prepare the business environment for the process of portfolio optimisation?

This section presents the research issue two, which deals with the preparation of the business environment for mathematically based portfolio optimisation. It is investigated which steps a portfolio manager has to conduct in order to prepare the business environment for portfolio optimisation. This investigation includes the question how software project data created with COCOMO II has to be adjusted in order for it to be able to use such data for the presented optimisation approach.

### 3.2.2 Research Issue Three: Generic Model

---

How could the portfolio optimisation environment, with its various goals and restrictions, be modelled in a generic formal model?

---

This section presents the research issue three. The goals listed above do show the characteristics a realistic optimisation model should support. The research issue three tries to create a formal model for portfolio optimisation, which is as general as possible, in order to provide a generic model for various business environments.

### 3.2.3 Research Issue Four: Optimisation Goals regarding Sequencing/Synergy

---

How could general portfolio optimisation goals XVIII, IX be supported by the optimisation approach?

---

This section presents the research issue four. Published approaches to the field of portfolio optimisation are discussed, and research issue four is defined. The portfolio optimisation approaches analysed in section 2.6 do consider different objectives, constraints and restrictions in their process of calculating the pareto-optimal front. All of them use some kind of potential revenue maximisation, various logical constraints, and some kind of restrictions. The approach presented in the paper *Interactive R & D Portfolio Analysis with Project Interdependencies and Time Profiles of Multiple Objectives* [42], considers the resource consumption in its corresponding timeframe, which is especially important for creating a realistic portfolio optimisation model. Synergy Effects between projects are considered in the optimisation approach presented in the paper *Pareto ant colony optimization: A metaheuristic approach to multiobjective portfolio selection*, [14]. Out of the author's view, the consideration of projects which could be selected for different timeframes is especially important. This important characteristic of a portfolio optimisation model is only considered in the paper [16]. Since the projects could be selected for an arbitrary timeframe, given that the project is completed within the planning horizon, the proposed optimisation process seeks to expand this idea to restrict the possible starting timeframes of the projects, and thus supporting goal XVIII.

It seems that in [14], only positive synergy effects are regarded. The presented approach expands this idea to the consideration of negative synergy effects as well, and thus supporting goal XVIII.

This approach tries to consider all relevant goals for a portfolio optimisation approach found in the theory about PPM, and the analysed papers about mathematically based portfolio optimisation. Thus, the presented approach should provide a realistic portfolio optimisation model which includes all presented and required characteristics, and expands the generally used techniques with two new methods. These two new methods are presented above, and are the consideration of the fact that projects may start in exactly one, a few, or an arbitrary number of timeframes, and the consideration of negative synergy effects.

## 3.3 Evolutionary Algorithms

This section presents the reason why an evolutionary algorithm is used for the presented optimisation approach. Three goals of the optimisation approach are presented. The decision that in this thesis an evolutionary algorithm is applied to the project selection problem, is strongly influenced by the optimisation approaches presented in section 2.6. These approaches have proven that integer linear programming models, pareto ant colony optimisation, and genetic algorithms are generally applicable to the project selection problem.

The choice to use an evolutionary algorithm for the creation of efficient portfolios is influenced by these approaches and the general applicability of mPOEMS to multi-objective problems. This section presents the research issues which deal with the field of evolutionary algorithms.

### 3.3.1 Research Issue Five: Feasibility of mPOEMS

---

Is the Evolutionary Algorithm mPOEMS suitable to solve the project selection problem?

---

The choice of mPOEMS to apply it to the project selection problem is based on mPOEMS general applicability to solve multi-objective problems. Research Issue Five investigates whether mPOEMS is suitable to solve the project selection problem, with its potentially great number of objectives and various constraints.

### 3.3.2 Research Issue Six: Adapt mPOEMS to Portfolio Optimisation

---

Which steps have to be conducted to adapt the Evolutionary Algorithm mPOEMS to solve the project selection problem?

---

This research issue deals with the implementation details of adapting the mPOEMS framework to the formal model of the project selection problem. It should be presented how the mPOEMS framework has to be adjusted, that it can be used to solve complex problems.

### 3.3.3 Research Issue Seven: Performance of mPOEMS

---

How does mPOEMS perform for the project selection problem, in comparison to state-of-the-art Evolutionary Algorithms?

---

The comparison of the performance of mPOEMS for the given problem, with different search and optimisation algorithms, is necessary to judge the quality of the pareto-optimal front found by mPOEMS. If this comparison would not be executed, one could not be sure if there do not exist solutions in the search space which dominate solutions on the pareto-optimal front found by mPOEMS.

## 3.4 Group Decision and Visualisation

This section summarises the research issues regarding group decision and visualisations.

The authors of the paper *Project portfolio selection through decision support* [16] and *Interactive R & D Portfolio Analysis with Project Interdependencies and Time Profiles of Multiple Objectives* [42], presented in the related work section 2.6, claim that further research should be done in applying the presented decision support system to group decisions.

Based on these statements for further research, found in well accepted papers for the project selection problem, the following research issues have been defined.



### **3.4.1 Research Issue Eight: Group Decision Process**

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How could the process of selecting one portfolio out of the pareto-optimal front be adapted to a group of decision makers?

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This research issue is especially important, since decisions with such a high significance for a business are mostly conducted in a group setting.

### **3.4.2 Research Issue Nine: Visualise multi-dimensional data**

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What are suitable visualisation and data exploration techniques for the group decision process?

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The research issue number nine deals with the question of whether sophisticated visualisation and data exploration techniques could be used to support decision makers in the selection of one portfolio.

### **3.4.3 Research Issue Ten: Insertion of Individual Preferences**

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How could individual preferences be easily inserted into the group decision process?

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Research Issue Number Ten investigates how individual preferences of decision makers participating in the group decision process could be inserted into the process.

This chapter summarises the research issues which are dealt with in this thesis. The approach to conduct the research is presented in the next chapter.

## 4 Approach

As already mentioned, the structure of this thesis follows the structure of CIDECS. Thus the usefulness of CIDECS to help a model designer to approach a complex decision problem will be investigated in creating this thesis. If the structure used supports the author in the process of modelling the proposed framework for the project selection problem, CIDECS is considered as helpful to model complex decision problems. This point of research, which is actually research issue one presented in chapter 3.1.1.

The first steps of CIDECS are conducted in chapter 5. *Decision model definition* is the first CIDECS step and deals with creating and defining a preferably realistic model of the problem environment. This includes definition of the problem structure, available goals and potential constraints. Existing decision models and available data concerning the problem area serve as input data to this step. The created decision model is the input for the step *Utility model Cost-benefit definition*. In this step, stakeholders define performance measures. Chapter 5 is named after the output of the first two CIDECS steps, which is *Decision & Goal Model*.

In the chapter mentioned a preferably realistic model of the problem environment is created in proposing a PPM process in section 5.1, which is focused on the steps a PPM manager has to conduct, in order to prepare the business environment for mathematically based portfolio optimisation. The proposed process also includes steps which have to be carried out to conduct portfolio optimisation, choose one alternative of the potentially great number of pareto-optimal portfolios, adjust this portfolio manually, and consequently conduct the selected portfolio. Furthermore, the *Decision & Goal Model* chapter includes a formal model in section 5.2.1. This formal model defines on the one hand the definition of the problem structure, available goals and potential constraints, and on the other hand performance measurements in a general manner. Since the proposed PPM process and the formal model is based on the goals listed in 3.2, which are in turn based on the theory of PPM and well accepted papers, the chapter *Decision & Goal Model* uses existing decision models and available data as input data for the process of creating a decision & goal model.

The research issues two to four are processed in the chapter mentioned. Through the presentation of a PPM process, which answers the question which steps a decision maker has to conduct to prepare the business environment for portfolio optimisation, research issue two is covered. Research issue three is dealt with in chapter 5.2.1, in creating a formal model of the portfolio environment, including the definition of the problem structure, goals, various constraints, and restrictions. Research issue four is dealt with in the created formal model, proposing a way to restrict the possible starting timeframes of projects. In order to provide the used evolutionary algorithm with the possibility to optimise the selection of projects regarding timeframes, the solution representation is expanded from only encoding the information about whether a project is selected for a portfolio or not, to the possibility of selecting the starting timeframe of the projects, out of the list of possible starting timeframes of each project. This is done by expanding the commonly used 0-1 solution representation vector, to a *0-possible starting timeframes* solution representation vector. Furthermore, a minimisation objective to consider negative synergies between projects is introduced. In order to reduce the number of objectives, the use of a combined synergy maximisation objective is proposed, which deducts the negative synergy from the positive synergy of a solution. This combined synergy metric is used in test runs on test data, presented in the research evaluation framework in chapter 7.

The CIDECS steps *Alternative Generation* and *Alternative reduction* are covered in chapter 6 and 7. Chapter 6 does show how mPOEMS has to be adapted to solve the project selection problem. Based on the formal model definition, implementation details of the evolutionary approach to project selection are presented. Thus, chapter 6 deals with research issue six, and answers it in presenting the steps on how mPOEMS has to be adapted to solve the project selection problem.

The research issues five and seven are dealt with in chapter 7, which is named *Research Evaluation Framework*. This chapter presents the used test data and various configurations. Results will be presented for a test set with fifty software development projects. The analysis of these results will show whether mPOEMS is suitable to solve the given project selection problem, thus presenting the answer for research issue five. The answer for research issue seven is presented in section 7.3.4, comparing the results of mPOEMS with results found by the state-of-the-art optimisation algorithms NSGA-2 and SPEA-2. Chapter 7 also includes the answer for the question of how software project data created with COCOMO II has to be adjusted to be able to use such data for the presented optimisation approach, in presenting the details of creating the test data in section 7.1. This question is a part of research issue two.

The research issues eight to ten are dealt with in chapter 8, *Interactive Visualisation & Discussion*, named after the corresponding CIDECS step. The chapter mentioned includes the presentation of a group decision process for the selection of one portfolio out of the pareto-optimal front, thus presenting an answer to research issue eight. This presentation of a group decision process includes the presentation of suitable visualisations and data exploration techniques. Thus, research issue nine is dealt with in this chapter, seeking an answer to the question of how the group decision process could be supported with visualisations and data exploration techniques. The core of the presented group decision process is a decision model, including decision rules and preference functions. These preference functions will map preferences of decision makers to numbers, which are consequently used in the visualisation of the portfolio data, encoded as colour and size. This introduction of the quantitative measurement of preferences, instantly enables decision makers in the group decision process to choose portfolios based on a consent of all decision makers participating in the selection process, in an easy and uncomplicated way. Thus, research issue ten is dealt with in this chapter.

After presenting the approach to create the project portfolio decision support model, the next chapter presents the first CIDECS step, *Decision & Goal Model*.

## 5 Decision & Goal Model

This chapter presents a realistic model of the portfolio decision support environment, especially focused on the creation of optimised portfolios. Therefore, a PPM process is created, which is focused on the steps a PPM manager has to conduct, to prepare the business environment for mathematically based portfolio optimisation. Furthermore, a formal model of the project portfolio optimisation environment is presented, including the definition of the problem structure, available goals, potential constraints, and various performance measures. The research issues two till four are processed in this chapter. The presented PPM process answers the question of research issue two about which steps a decision maker has to carry out to prepare the business environment for portfolio optimisation. Research issue three is covered in presenting the formal model. The consideration of the possible starting timeframes of projects and the presentation of the synergy heuristic, in the formal model, cover research issue four.

### 5.1 The Project Portfolio Management Process

The proposed PPM process, with focus on the evolutionary optimisation approach, utilised in the process step *create efficient portfolios*, is presented consequently.

This PPM process is divided into ten distinct steps, presented in figure 5.1. It is assumed that projects are administrated in a central database. The project table comprises all defined key characteristics and estimated resource/cost consumption per defined timeframe.

#### 5.1.1 Strategy Ranking

Input: Strategic Plan  
Output: relative ranking of the strategies  
Supported Goal: X XIV

In the first step of this PPM process, the strategies defined on the executive level are ranked according to the wishes of the decision makers. AHP is well suited for this task,

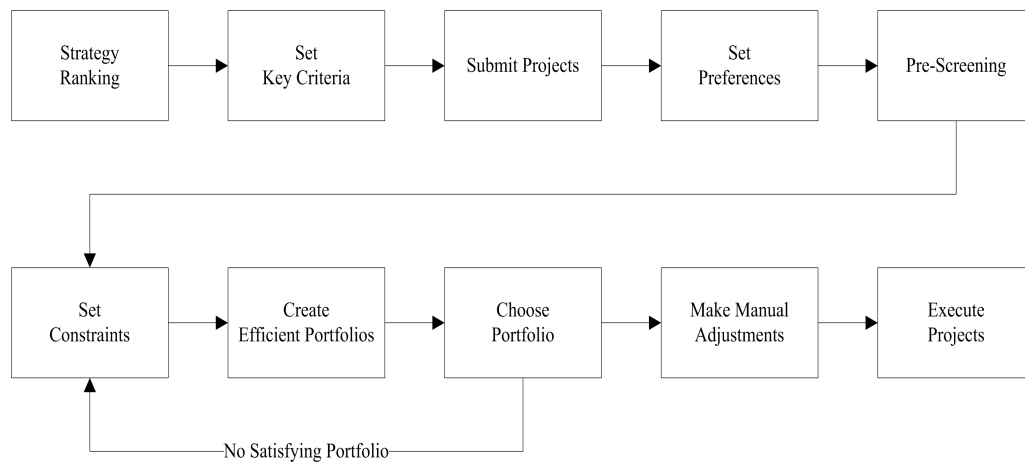


Figure 5.1: Proposed PPM Process

whereas any formal and informal methodology can be used to create a relative ranking. It is important that the ranking is combined with a weighting of the strategies, in order to be able to calculate a project SAV. The algorithm will optimise the created portfolios, considering the SAV values of the projects.

### 5.1.2 Set Key Criteria

Input: Evaluation Criteria, Categories

Output: Defined Criteria for the portfolio, Submission Sheet

Supported Goal: XI XIII IX XIX

The second step uses the evaluation criteria and categories defined in the strategic plan as an input. Criteria is selected in order to define the scheme against which proposed projects will be evaluated. A list of possible criteria is found in chapter 2.5.2.

The set of criteria should contain at least one financial metric, like ROI or NPV. The use of a financial metric provides the algorithm with the possibility of maximising the potential financial return of the suggested portfolios.

It is suggested that at least one risk metric be used in order to conduct proper portfolio risk management. The use of a risk metric provides the algorithm with the possibility of optimising the portfolio towards the risk preferences of the decision makers. Preferences concerning key criteria and categories are presented in the "Set Preferences" process step.

Furthermore, the key criteria should comprise negative and positive synergies of projects, in order to force stakeholders to recapitulate the impact of a project to other projects be they, negative or positive. This impact should be noted and defined with predefined values. The numbers 9 for high-impact, 6 for medium impact and 3 for small impact could

be used. Monetarily describing the synergy would be possible as well. This information is used by the algorithm to optimise portfolios, regarding maximised positive synergies and minimised negative synergies.

An important point is the definition of categories. The definition of categories provides the algorithm with the possibility of optimising the distribution of projects towards the preferences of the decision makers.

The list of criteria should be combined in one submission sheet and projects should be presented in consideration of this scheme. Besides the presented key criteria, it is worth mentioning that any quantitative measurable criteria can be used for the project submission sheet. This is especially important for providing a process and optimising algorithm that is adjustable to various business environments.

### 5.1.3 Submit Projects

Input: Projects which should take part in the selection process  
Output: List of proposed projects  
Supported Goal: V

Projects are either selected from the database, or new projects are added into the database. The projects should provide data for at least all key criteria.

The outcome of this process step is a list of all projects which take part in the process of selecting projects and create optimised portfolios.

### 5.1.4 Set Preferences

Input: Defined Criteria for the Portfolio, Submission Sheet  
Output: Defined Preferences  
Supported Goal: XI XIII VI VIII IX XIX

Based on the defined criteria and categories, preferences for this data have to be defined. This could be done by defining a percentage for each category. For example, a portfolio should comprise approximately sixty percent in projects from category A, twenty-five percent in projects from category B and fifteen percent from category C.

Risk preferences could be set to either minimise overall risk, while maximising potential revenue, or to create portfolios which have a certain balance between risk and revenue. To obtain a certain balance, decision makers should define approximate values for the number of high-risk projects, mid-risk projects and projects with low-risk. The algorithm will use this numbers to optimise the portfolio towards the desired distribution.

In the latter case, the algorithm uses the values in the same way as to create the distribution for the categories. The same approach can be used to define preferences concerning time-related returns, for example, to prefer short-term vs. long-term returns.

These preferences are referred to as "soft-preferences", because in most cases, decision makers will not have exact preferences regarding these values.

The so called "hard-preferences" have to be followed exactly. Hard-preferences can be must-vote restrictions or logical relationships between projects. Hard-preferences have to be strictly adhered to. An example of a hard-preference concerning logical relationships would be if one project can be conducted only if another project is in the same portfolio.

### 5.1.5 Screening

Input: List of proposed projects  
Output: Adjusted list  
Supported Goal: XII

This step filters and presents projects which do not meet defined criteria. An criterion could be that data for each key criterion has to be available, including estimates for resource and cost consumption. The projects that do not meet the defined criteria are either rejected, or the project stakeholder is asked to submit the missing data.

This process can be used as well to check and adjust project data from certain projects, especially projects which are important from the decision maker's point of view.

### 5.1.6 Set Constraints

Input: Resource Plan, Available Budget  
Output: Various constraints  
Supported Goal: XVI XVII

Due to limited resources and budget per timeframe, constraints have to be defined. The algorithm to create efficient portfolios will take these constraints into account.

These constraints can be modelled either as hard-constraints, at which portfolios violating constraints are deleted, or as soft-constraints which can be violated. When using soft-constraints, the unavailable resources (staff, budget) per timeframe will be either minimised by the algorithm, or like in the proposed optimising algorithm, portfolios which violate constraints are repaired by a repair algorithm. This repair algorithm removes projects from portfolios, until all constraints are adhered to. Projects are removed, based on their



revenue / needed resources ratio, whereas any other ratio or characteristic of a project can be used to select projects which are to be removed first.

### 5.1.7 Create Efficient Portfolios

Input: Adjusted list of proposed projects  
Output: Efficient frontier of portfolios  
Supported Goal: VIII IX X XIV XI IX XIII XV XVI XVII XIX

The list of all proposed projects serves as input to the step of creating portfolios. Efficient portfolios are created through the selection of projects out of the pool of proposed projects. Since the selection and arrangement of projects is a complicated task, when overall criteria, goals and various restrictions should be optimised, this makes automated, optimising algorithms well suited for creating efficient portfolios.

In the optimisation approach presented in this thesis, an evolutionary optimising algorithm, namely mPOEMS, is used to create and optimise portfolios. In chapter 5.2.1, the formal model for the problem-dependent optimisation part, is presented. The evolutionary algorithm used is presented in chapter 2.7. Results and the proof-of-concept are shown in chapter 7.

The output of this process step is a list of efficient portfolios, from which the decision makers have to choose one portfolio.

### 5.1.8 Choose Portfolio

Input: Efficient frontier of portfolios, Individual Preferences  
Output: Selected Portfolio  
Supported Goal: VII

Out of the set of efficient portfolios, one portfolio has to be chosen. Since this is also not a trivial task, the use of a structured approach is suggested. This process should be applicable to one decision maker, or a group of decision makers. A group decision process is presented in chapter 8, supporting decision makers in choosing a portfolio in visualising the characteristics of the portfolios, and the preferences of each individual participating in the decision process.

### 5.1.9 Make Manual Adjustments

Input: Selected Portfolio  
Output: Adjusted Portfolio

Optimisation and decision frameworks are always models of reality and will never contain all available information. Therefore, a process to create and select portfolios should provide decision makers with the ability to make manual adjustments to the selected portfolio.

Manual adjustments should be directly connected to visually presented feedback on the resulting consequences [1]. This thesis does not propose a method of how to implement this feature. This part of the process should be subject to further investigation and research.

### 5.1.10 Execute Projects

Input: Adjusted Portfolio  
Output: Data from field

In the last step, the selected projects will be conducted, and data from the field will be gathered. Data from the field could improve further decision making.

After the presentation of the PPM process, focused on the optimisation of portfolios, the formal model for mathematically based portfolio optimisation is presented consequently.

## 5.2 Mathematically based portfolio optimisation

The process step *Create Efficient Portfolios*, proposed in the PPM process in chapter 5.1, utilises an evolutionary algorithm, combined with some meta-heuristic features, to create optimal portfolios. The formal model to create such a portfolio optimisation implementation is presented below.

### 5.2.1 Formal Model

The presented project selection problem is similar to the knapsack problem presented in [51]. The designated goal of the presented knapsack problem is to find a subset of items for an arbitrary number of knapsacks, which maximise the profit for each knapsack, while the maximum capacity of all knapsacks under consideration may not be exceeded.

A solution is represented by a vector with the length of the maximum available items, where position  $i$  is 1 if item  $i$  is selected, and 0 if not. Selecting projects from a pool of potential candidates is basically the same as selecting items from a set of items. With the addition, that projects are described, not only with the information, whether a project is selected ( $x_i > 0$ ) or not ( $x_i = 0$ ), but as well with the information when the project start (value of  $x_i$  greater than 0). The planning horizon of a portfolio is subdivided into timeframes, and timeframes are in turn subdivided into smaller units. These units can be chosen arbitrarily. Months are used here for these units, and one year for the timeframes. The project start is declared by selecting a month for each project from the available planning horizon.

Therefore, the task of the project selection problem is to find a vector

$$x = (x_1, x_2, \dots, x_p) \in M_i$$

$$M_i \subseteq M$$

$$M = (0, 1, 2, \dots, T \cdot 12)$$

where  $x_i$  is greater 0 if project  $i$  is selected, and 0 if not,  $p$  is the number of projects in the candidate pool,  $M$  the number of months in the planning horizon,  $M_i$  the months in which project  $i$  can start, and  $T$  the number of timeframes in the planning horizon. For the sake of simplicity in presenting the formal model, a variable  $w_i$  is introduced, which has the value 1 if project  $i$  is selected, and 0 if not.

The search for a vector that represents the selected projects for a portfolio is subject to four different optimisation criteria, and various logical constraints. The four optimisation criteria are namely maximisation, minimisation, soft preferences and hard preferences.

**Maximisation** The maximisation part uses the financial metric, which describes the potential financial revenue of a project, as input to project selection, and the algorithm seeks to maximise the overall potential financial revenue of the portfolio. Thus the maximisation function may be expressed as,  $f(x) = (f_1(x), f_2(x), \dots, f_p(x))$  is maximum, where

$$f_i(x) = r_i \cdot w_i \tag{5.1}$$

and  $r_i$  is the potential financial revenue of project  $i$ , and  $w_i$  is 1 if project  $i$  is selected, and 0 if not.

Furthermore, strategic alignment is subject to maximisation. Each proposed project

should have a strategic alignment value attached. This value can be created as proposed in the sub chapter 2.5.4. Overall strategic alignment maximisation on the portfolio level may be expressed as,  $s(x) = (s_1(x), s_2(x), \dots, s_p(x))$  is maximum, where

$$s_i(x) = a_i \cdot w_i \quad (5.2)$$

and  $a_i$  is the strategic alignment value of project  $i$ , and  $w_i$  is 1 if project  $i$  is selected, and 0 if not.

Synergy effects are often described in monetary units, or, as proposed in chapter 5.1.2, as values on a predefined scale. In either way, for the case of positive synergy effects, the goal of the algorithm is to maximise the positive synergy value of the portfolio. For the case of negative synergy effects, the goal is to minimise the effects. Negative synergy effects are presented below.

Mathematically, the relationship for positive synergy effects may be expressed as,  $y(x) = (y_1(x), y_2(x), \dots, y_p(x))$  is maximum, where

$$y_i(x) = \sum_{k=1}^K (y_{i,k} \cdot w_i) \cdot w_k \quad (5.3)$$

$$k \in K$$

and  $y_{i,k}$  is the positive synergy value of project  $i$  concerning project  $k$ ,  $w_i$  is 1 if project  $i$  is selected, and 0 if not,  $w_k$  is 1 if project  $k$  is selected, and 0 if not, and  $k$  is an element of  $K$ , which is the set of projects selected as potential candidates for positive synergy between a candidate and at least one other project.

In order to reduce the number of objectives that have to be considered in the optimisation approach, it is possible to combine the negative synergy and the positive synergy to one maximisation objective. For this purpose, the sum of negative synergy is subtracted from the sum of positive synergy, consequently referred to as the *synergy* of a solution. This optimisation criterion is used in the test runs, presented in the chapter 7. A small number of objectives is desirable, because it simplifies the process of finding solutions which dominate other solutions.

**Minimisation** Negative synergy effects are one example for minimisation used in the step of creating efficient portfolios. These effects negatively affect the value of a portfolio, and should be minimised. Mathematically, the relationship for negative synergy effects may be expressed as,  $z(x) = (z_1(x), z_2(x), \dots, z_p(x))$  is minimum, where

$$z_i(x) = \sum_{l=1}^L (z_{i,l} \cdot w_l) \cdot w_l \quad (5.4)$$

$$l \in L$$

and  $z_{i,l}$  is the negative synergy value of project  $i$  concerning project  $l$ ,  $w_i$  is 1 if project  $i$  is selected, and 0 if not,  $w_l$  is 1 if project  $l$  is selected, and 0 if not, and  $l$  is element of  $L$ , which is the set of projects selected as potential candidates for negative synergy between a candidate and at least one other project.

**Soft Preferences** Minimisation or maximisation is used to consider soft preferences in the step of creating efficient portfolios. This is done by formulating a preference-specific function, which either returns a number to be minimised or to be maximised. In the case of a preference concerning a balanced portfolio regarding categories, a preference-specific function could return a value that describes the difference between a solution and the desired distribution. The higher the value of the returned number, the greater the difference. Therefore, the preference regarding a balanced portfolio may be expressed as an objective function to be minimised.

To calculate the number of projects in a solution that are assigned to a specific category  $d_j$ , the following equation is used,

$$d_j = \sum_{i=1}^p c_{i,j} \cdot w_i \quad (5.5)$$

$$\text{for } j = 1, \dots, C$$

where  $c_{i,j}$  is 1 if project  $i$  is assigned to category  $j$ , 0 if not,  $w_i$  is 1 if project  $i$  is selected,  $C$  is the number of distinct categories, and  $d_j$  is the number of projects in a solution assigned to category  $j$ .

Consequently, the objective function to minimise, may be expressed as

$$\sum_{j=1}^C f_j \cdot e_j \quad (5.6)$$

where  $e_j$  is the desired percentage share of projects of category  $j$  in a portfolio, and  $f_j$  is the percentage difference of projects from category  $j$  in a portfolio, to the desired percentage share  $e_j$ .  $f_j$  is multiplied by  $e_j$  to take the weight of each category into account, and therefore enforce the selection of portfolios, which contain more projects of categories with a higher desired percentage share.

$f_j$  can be calculated following the next equation,

$$f_j = \frac{d_j}{p} - e_j \quad (5.7)$$

where  $d_j$  is the number of projects in a solution assigned to category  $j$ ,  $p$  is the number of projects in the candidate pool, and  $e_j$  the desired percentage share of projects of category  $j$  in a portfolio.

Since this approach is subject to optimisation, a broad range regarding the number of projects assigned to a specific category can be expected. In order to create mainly portfolios, where the number of projects assigned to a specific category is similar to the desired percentage distribution, this category objective can be transformed into a restriction. This restriction will use the desired percentage distribution as an input, and will set the fitness of solutions, which have a category objective higher than a certain value, to zero. Since this is a strict restriction, users should be sure not to be too restrictive when setting the value that determines whether a portfolio is valid or not. This approach will ensure on the one hand the creation of portfolios with certain characteristics, and on the other hand will provide the user with a tool to control how restrictive a preference should be.

This approach can be used for any preference. Risk and long-term vs. short-term results are distributions well suited to this approach. Percentage distribution can be easily attained for the risk metric, if risk is quantitatively described, and the desired distribution of low, medium and high risk projects in a portfolio is determined. If a qualitative risk metric is used, the approach is similar. The qualitative risk metric presented in [9], is defined as a percentage value, describing the overall risk of a project, which was calculated by the weighting of different factors and the median of risk-related questions. In order to attain a portfolio-level risk balance, in the case of using a qualitative risk metric, decision makers have to define a desired median risk value. Another possibility is to partition the percentage range into a first third for low-risk projects, a second third for medium-risk projects, and the last third for high-risk projects. In the first case, the preference-specific function returns the distance between the desired median risk value and the median risk value of a portfolio, which, in turn, the algorithm will try to minimise. In the latter case, the preference-specific function works the same way as described for the percentage distribution, presented above.

Both category distribution as a restriction and median risk value are considered as so-called soft preferences in the test runs.

**Hard Preferences** Unlike soft preferences, hard preferences have to be strictly adhered to. Must-vote restrictions of projects, logical relationships between projects, and mutually exclusive projects, are such preferences.

Preferences concerning the obligatory selection of certain projects (must vote prefer-

ences), or the obligatory selection of certain projects dependent on the integration of another project (logical relationship), are adhered to, in either restricting the value of the corresponding position in the solution vector, or using repair algorithms.

Must-vote restrictions are adhered to, in prohibiting the use of the value 0 for the corresponding position in the vector, which would mean that the project is not selected.

Preferences concerning logical relationships are more complex. Logical relationships are not restricted to a specific number of projects. If such a logical relationship is violated, a repair algorithm will include the direct predecessor. This algorithm repeats its procedure until all logical relationships are fulfilled. The insertion is conducted in a way that the inserted project will finish in the timeframe before the project that triggered the repair algorithm would start. If the insertion cannot be successfully accomplished, maybe because the insertion would be in a timeframe lesser than 1, the attractiveness of a portfolio will be manipulated. In terms of the evolutionary algorithm mPOEMS, the fitness of the portfolio will be set to 0, and therefore the portfolio will no longer take part in the selection process.

In the case that all logical relationship preferences are fulfilled, an algorithm has to check whether a start-to-finish constraint is violated. A start-to-finish constraint is violated if project B is the successor of project A, project A finishes in month  $m_i$  and project B starts in  $m_{i-1}$ . The algorithm would, in this case, change the starting month of project B to a month greater than  $m_i$ , which is included in the subset  $M$  of months in which project B may start.

After each of the last two procedures, the algorithm presented in the *constraints* paragraph will repair possible resource violations.

Hard preferences concerning mutually exclusive projects can lead to the creation of many invalid portfolios. In order to fulfil these preferences, a repair algorithm, which removes projects that violate a hard preference, will be implemented. Projects with the worst potential revenue/needed resources ratio will be removed first.

**Constraints** The selection of projects for a portfolio can be restricted by various constraints, regarding available resources and budget. Portfolios violating hard constraints have to be modified by a repair algorithm.

Constraints may be expressed as,

$$\forall o \in O \& \forall t \in \{1, 2, \dots, T\} : \sum_{i=1}^p r_{o,t,i} \cdot w_i \leq R_{o,t} \quad (5.8)$$

where  $o$  is the type of resource,  $O$  the set of resource types under consideration,  $t$  the timeframe,  $T$  the number of timeframes in the planning horizon,  $r_{o,t,i}$  the type  $o$  resource

consumption of project  $i$  in timeframe  $t$ ,  $w_i$  is 1 if project  $i$  is selected, and  $R_{o,t}$  the type  $o$  resource restriction in timeframe  $t$ . It is worth mentioning that the budget is considered as one of the resource types, subject to resource restrictions.

Portfolios violating one of these constraints have to be repaired by an algorithm. The algorithm used for the resource constraints removes projects with the worst potential revenue/needed resources ratio, first. The removal is repeated until all resource constraints are fulfilled.

In order to create selection pressure towards the selection of portfolios which on the one hand have a high resource usage per timeframe, and on the other hand have the best distribution between the timeframes, an objective to maximise is introduced. This objective is called Resource Usage Distribution Metric (RUDM). Its value is between 0 and 1, where 1 means full resource consumption in each timeframe, and 0 means that at least in one timeframe no resources are consumed.

Consequently, the objective function to maximise, may be expressed as,

$$\prod_{t=1}^T \left( \frac{\sum_{i=1}^p r_{o,t,i} \cdot w_i}{R_{o,t}} \right) \quad (5.9)$$

where  $o$  is the type of resource,  $t$  the timeframe,  $T$  the number of timeframes in the planning horizon,  $r_{o,t,i}$  the type  $o$  resource consumption of project  $i$  in timeframe  $t$ ,  $w_i$  is 1 if project  $i$  is selected, and  $R_{o,t}$  the type  $o$  resource restriction in timeframe  $t$ . For each resource type under consideration, an objective to maximise should be introduced in order to ensure proper analysis of the resource consumption behaviour.

The presented formal model is used to apply the EA mPOEMS to the project selection problem, thus creating an optimisation framework especially designed for PPM. The next chapter shows how mPOEMS has to be adapted in order to use it for creating optimised portfolios.



## 6 Alternative Generation & Reduction

This chapter shows how mPOEMS has to be adapted to solve the project selection problem. Based on the formal model definition, implementation details of the evolutionary approach to project selection are presented. Therefore this chapter deals with and answers research issue six, while presenting the steps on how mPOEMS has to be adapted to solve the project selection problem.

**mPOEMS for Project Selection** To use mPOEMS for a specific problem, the problem specific part has to be designed and implemented. Problem specific are the representation of a solution, actions which modify a solution, genetic operators used in the evolution of the actions, and the values of the configuration values. A previously implemented, generic JAVA framework of mPOEMS is used [24], where the problem-dependent parts can be easily attached. The implementation of the problem dependent part for project selection follows the definition presented subsequently.

**Solution representation** As mentioned in the description of the formal model 5.2.1, the solution is represented by a vector, where each position describes whether a certain project is selected or not. Additionally, the information concerning in which timeframe the project should start, is provided.

**Actions** The definition of proper action types is of special importance, because the actions are the vehicles by which the solution space will be traversed. A non-appropriate action choice can lead to solutions, prone to stack in local optimums. A good action choice will ensure traversing of the entire solution space, as well as sufficient exploration capabilities [26].

For the project selection problem, two actions, called *changeMonth* and *switchOnOff*, are introduced. The *changeMonth* action changes the starting month of a project randomly to another month, with respect to the valid timeframes for the project under consideration. Initialisation and the mutation of this action is done randomly, with the restriction, that the *month* value has to be selected, out of the set of valid starting months for the project under consideration.

In order to provide the algorithm with the ability to switch off and switch on projects, the *switchOnOff* action is introduced. Tests have shown that the *changeMonth* action is not sufficient, because the value zero, which means the project is not selected, has a very low probability of being selected for the *changeMonth* action parameter. This is due to the fact that a lot of projects have more than one starting possibility. The *switchOnOff* action selects a project if it is unselected, and vice versa. Initialisation and the mutation of this action is done randomly, with the restriction that this action will not be applied to projects which are mandatory.

**Genetic Operators** The crossover operator is used as proposed in [27]. Each gene of both parents have the same probability of being selected for the offspring. Valid offspring constitutes an arbitrary combination of parental actions, whereas each gene can be used only once. The mutation operator either changes the *projectID*, or the *timeframe* parameter of an action.

Tournament selection is used for selecting the parents, and consequently creating an offset in the *evolutionaryCycle*. A tournament is held by the candidates, and the chromosome with the best fitness will be selected to be one of the parents. The candidates are chosen randomly from the old population of chromosomes. To which degree better individuals are favoured can be determined by the number of candidates taking part in the tournament. The more candidates, the more selection pressure is created towards the selection of better candidates. *nTournament* is the corresponding configuration value for the mPOEMS framework, determining the number of candidates. Selection pressure should not be too low, because this would lead to a slow convergence rate. But the selection pressure should as well not be too high, because this increases the probability of converging to a sub-optimal solution [35].

**Configuration** A few values to configure mPOEMS, like *nIterations*, *nGenerations* and *nTournament*, are already mentioned above. mPOEMS provide some more configuration values. All configuration values are presented below.

#### **mPOEMS configuration**

- *nIterations* is the termination condition of mPOEMS. This configuration value defines the number of iterations conducted by the mPOEMS framework.
- *sbSize* defines the size of the solution base.
- *pActive* defines the percentage of actions, which will be initialised as active actions. Thus this configuration value set to 75 would lead to 25-percent non-active actions in a mPOEMS run.

- *seed* defines the seed configuration value for the random number generator. The use of a seed value ensures exactly the same sequence of random values, and therefore the creation of exactly the same results in different runs, given that the configuration values are not changed.

### **MOEA configuration**

- *nGenerations* is the MOEA termination condition.
- *popSize* defines the size of the population of ActionSequences, created in step one of the MOEA.
- *maxGenes* defines the number of actions included in one ActionSequence.
- *pM* defines the probability of mutation for each ActionSequence, selected by Tournament Selection.
- *pC* defines the probability of crossover for the ActionSequences, selected by Tournament Selection.
- *pBitflip* defines the probability of mutation for each Action of an ActionSequence, which was selected for mutation.
- *nTournament* defines the number of candidates, which take part in the Tournament Selection.

### **Optimisation Problem configuration**

The configuration values for the problem to solve are presented in this section.

- *nObjectives* defines the number of objectives for the optimisation problem.
- *ObjectiveN* defines whether an objective has to be maximised or minimised. *N* has to be exchanged with the number of the objective. For each objective a configuration value has to be defined. Therefore, *N* ranges from one till *nObjectives*.

The implemented mPOEMS approach to project selection is applied in the next chapter with a test set of fifty projects. Creation of the test set is presented, and the results are analysed. The next chapter therefore presents the proof-of-concept for the presented evolutionary approach to portfolio optimisation.

# 7 Research Evaluation Framework

The research evaluation framework comprises the description and characteristics of the test data, relationships and constraints of the data, as well as an introduction about how the data is generated. Generated data is subsequently used to conduct test runs, and results of the test runs are presented and analysed.

The research issues five and seven are dealt with in this chapter. Analysis of the results found by mPOEMS will show whether mPOEMS is suitable for solving the given project selection problem, thus presenting the answer for research issue five. The answer for research issue seven is presented in section 7.3.4, comparing the results of mPOEMS with results found by the state-of-the-art optimisation algorithms NSGA-2 and SPEA-2. This chapter also includes the answer for the question of how software project data created with COCOMO II has to be adjusted, to be able to use such data for the presented optimisation approach, which is a part of research issue two. This research regarding the test data, created with COCOMO II, is presented below.

## 7.1 Test Data

In the previous chapters, project characteristics, which are especially important for the project portfolio selection process, have been identified. Financial and risk metrics are among them, as well as synergy effects and project inter-dependencies. The following listing presents the identified project data:

- Effort in Person Months  
The complete PM effort the project require
- Schedule in Months  
The duration of the project in months
- Personnel Effort or Cost per Month  
The complete effort or cost separated for each month

- Starting Months  
List of months in which the project may start
- Potential Revenue  
The revenue the project is likely to generate
- Category Membership  
List of categories the project belongs to
- Strategic Alignment Value  
The strategic alignment value calculated for this project
- Negative and Positive Synergy Effects  
Synergy effects that are created if two or more projects are selected for the same portfolio
- Project Interdependencies  
Some projects are only conducted if another project will be conducted as well
- Estimated Risk Value  
The estimated risk value of the project
- Mutually Exclusive Projects  
Some projects may not be in the same portfolio with another project
- Mandatory Projects  
Some projects are obligatory because of different reasons

These data sets will be generated using special methods, which are presented subsequently.

### **7.1.1 Cost and Schedule Generation**

The COCOMO II cost estimating framework is used to generate cost-and schedule-related data. First, the *Effort in Person Months*, for a project with a randomly generated number of SLOC, is calculated. Secondly, the *Schedule in Months* is established, and consequently the *Personnel Effort or Cost per Month* is calculated.

Restrictions for the randomly generated data are established to ensure the creation of realistic project data. Restrictions are set concerning the minimum and maximum number of SLOC, like as well the calculated duration of the project, whereas created projects which have a duration greater than the allowed duration are disregarded from the set of created projects.

The steps how the project data will be created are presented below, followed by an example that calculates the project data. The values for all constants are taken from the initial calibration of COCOMO II:

Step	Description	Further Information
1	randomly generate KSLOC	chapter 2.2.1
2	calculate $E$ with randomly selected SF ratings	use equation 2.4 use SF ratings from table 2.1
3	calculate $\prod_{i=1}^n EM_i$ with randomly selected cost driver ratings	use EM from table 2.2 excluding EM SCED
4	calculate effort in PM	use equation 2.3
5	calculate TDEV in months	use equation 2.5
6	calculate schedule and effort using MBASE phases	use percentual distribution from table 2.3
7	Map PM effort per phase to PM effort per month (PMM)	
8	calculate cost per month (CM)	PMM · Cost per PM

Table 7.1: Cost and Schedule Creation Steps

Except step 7, all steps should be self-explanatory. Step 7 is conducted to create effort estimates per month. These estimates per month will be used to sum the effort and cost per timeframe for a created portfolio, and are therefore the basis for considering the resource and cost restrictions per timeframe.

The following example presents the calculation of the data, using the approach presented in table 7.1.

**Step 1** The project is estimated to need 37 KSLOC.

**Step 2**  $E = 0.91 + 0.01 \cdot 17.63 = 1.0863$ . The SF ratings are presented in table 7.2.

Scale Factor	PREC	FLEX	RESL	TEAM	PMAT
Rating	Very Low	Extra High	Low	Very High	Nominal
Value	6.20	0.00	5.65	1.10	4.68

Table 7.2: SF Ratings

**Step 3**  $\prod_{i=1}^n EM_i = 0.60$ . The cost driver ratings are presented in table 7.3.

Cost Driver	RCPX	RUSE	PDIF	PERS	PREX	FCIL	SCED
Rating	Low	High	Nominal	High	Very High	Low	High
EM	0.83	1.07	1.00	0.83	0.74	1.10	1.00

Table 7.3: Cost Driver Ratings

**Step 4**  $PM = 2.94 \cdot 37^{1.0863} \cdot 0.60 = 89$

**Step 5**  $TDEV = [3.67 \cdot (89)^{(0.28+0.2 \cdot (1.0863-0.91))}] = 15$

**Step 6** Schedule and effort per phase is presented in table 7.4.

Phase	Effort in PM	Schedule in Months
Inception	5	1.88
Elaboration	21	5.63
Construction	68	9.38
Transition	11	1.88
Totals	105	18.75

Table 7.4: Schedule and Effort per Phase

**Step 7** PMM is presented in table 7.5 and 7.6

Month	1	2	3	4	5	6	7	8	9	10
PMM	2.67	2.79	3.73	3.73	3.73	3.73	3.73	5.46	7.25	7.25

Table 7.5: PMM for Months 1 to 10

**Step 8** CM for assumed 4000 Euro per PM are presented in table 7.7, 7.8 and 7.9

It is shown how COCOMO II is used to generate cost- and schedule-related project data. The following sections describe the generation of other project-related data.

### 7.1.2 Starting Months Generation

Elicited in goal XVIII and the corresponding theory, projects may start in an arbitrary number of timeframes, in a few distinct timeframes, and in exactly one timeframe. The

Month	11	12	13	14	15	16	17	18	19
PMM	7.25	7.25	7.25	7.25	7.25	7.25	7.10	5.87	4.52

Table 7.6: PMM for Months 11 till 19

Month	1	2	3	4	5	6	7
CM	10667	11179	14933	14933	14933	14933	14933

Table 7.7: CM for Months 1 till 7

timeframes have to be chosen in a way such that the project will be finished in the planning horizon. Since the timeframes are subdivided into smaller planning units, namely months, the task is to select the months in which the project may start. This is done randomly, following the restriction that the months have to be selected from the planning horizon, as defined in the formal model 5.2.1.

### 7.1.3 Potential Revenue Generation

The potential revenue of a project is generated in relation to the estimated cost of the project. The percentaged revenue is randomly selected, whereas the percentaged value is restricted to the maximum value of 150 percent, and to the minimum of 85 percent. The selection is uniformly distributed between 100 percent and the maximum value for projects which are estimated to generate a positive potential revenue. Each fifth project is selected to generate negative potential revenue. For this case, the selected value is uniformly distributed between 85 and 100 percent.

### 7.1.4 Category Membership Generation

Following the theory stated in goal XIII, each project should be related to at least one category. Furthermore, it is not likely that a project is related to more than 50 percent of the categories, and therefore the relation to categories is restricted to the maximum of half the number of the available categories. The selection to which categories a project is related is done randomly.

### 7.1.5 Strategic Alignment Generation

Generation of the strategic alignment value is done by following the approach presented in section 2.5.4. The weighting of table 2.7 is used, whereas the strategies are named from



Month	8	9	10	11	12	13
CM	21833	29013	29013	29013	29013	29013

Table 7.8: CM for Months 8 to 13

Month	14	15	16	17	18	19	Total
CM	29013	29013	29013	28403	23467	18069	420390

Table 7.9: CM for Months 14 to 19

strategy 1 to strategy 5. Each strategy is weighted randomly with the values presented in table 2.8. The weighting values will be selected randomly, and are nearly uniformly distributed. In order to reduce the value of the strategic alignment value, the value 0 is available twice in the weighting scale. Weighting and adding the selected values creates an overall strategic alignment value.

### 7.1.6 Synergy Effect Generation

A maximum number of thirty percent of all projects is selected to have synergy effects with exactly one project, divided into fifteen percent of the positive synergy and fifteen percent of the negative synergy. Projects which have synergy effects, as well as the projects which have to be selected for the same portfolio in which the synergy effects will take effect, will be selected randomly.

Each synergy effect is restricted to be at a maximum of 15 percent of the total cost of the project, which will trigger the synergy effect. Each generation of a random number returns a uniformly distributed number between 0 and the maximum value declared. When creating the synergy effect, the maximum value has to be 15 percent of the total cost of the project.

### 7.1.7 Interdependencies Generation

Project interdependencies are restricted to a maximum of three projects in one interdependencies chain. It must be assured, that a project, which is dependent from another project, may start in a month greater than the last starting month of the preceding project. Because of the complexity of this task, these project interdependencies are created manually.

### **7.1.8 Risk Generation**

For each project, an overall risk value is generated. The approach presented in 2.2.2 is used, and a percentaged risk value is randomly created. The risk value is restricted to be at least twenty percent, and at most eighty percent. The creation tends to evaluate projects with a high amount of estimated SLOC with higher risk, and vice versa.

In practice, the estimated SLOC will not be the only criterion for the risk value, and not each project with a high number of SLOC will be rated with high risk. This is true as well for the opposite case, where a low number of SLOC results in a low risk value. To take these circumstances into account, each third project is rated with a randomly created risk value, uniformly distributed on a scale from twenty to eighty percent.

### **7.1.9 Mutually Exclusive Projects Selection**

A number between 5 and 15 percent of all projects is selected to be mutually exclusive. The selection is conducted manually, and projects which are part of the same interdependencies chain may not be selected to be mutually exclusive. The combination of the project that will trigger a synergy effect for a project and the project which has the synergy effect may as well not be mutually exclusive.

### **7.1.10 Mandatory Projects Selection**

A number of 10 percent of all projects is selected randomly to be mandatory.

### **7.1.11 Testset Configuration Values**

The creation of a set of projects is restricted by a set of configuration values. The following listing presents these configuration values.

- Number of projects in the project pool
- Planning horizon in months
- Maximum and minimum SLOC of a project
- Maximum and minimum risk value of a project
- Maximum duration of a project in month
- The costs of one PM

### 7.1.12 Portfolio Data Creation

A few portfolio values have to be set by the decision makers. The following listing presents these values.

- Strategies
- Categories
- Available resources per timeframe
- Available budget per timeframe, and cost of a PM

## 7.2 Solution Quality Criteria

In order to be able to measure the quality of solutions, quality criteria is defined. Table 7.10 shows the name and the description of these criteria, derived from the maximisation or minimisation description of the formal model presented in chapter 5.2.1. It is worth mentioning that these criteria are created especially for the test set described above, and has to be adapted for another set of project data. To make things clear, we can say that solution A is better than solution B if solution A has a greater mean strategic alignment value than solution B, given that the mean strategic alignment value is the sum of the strategic alignment value of each project selected for this particular solution, divided by the number of selected projects. Since a solution is not defined by just one characteristic and cannot be optimal in each quality criterion, the domination concept, presented in chapter 2.7 comes into effect.

Name	Description
Potential Revenue	The greater the overall potential revenue, the better the solution
Strategic Alignment	The greater the overall strategic alignment value, the better the solution
Resources	The closer the RUDM is to one, the better the solution. See also equation 5.9
Risk	The lesser the deviation from the desired risk range, the better the solution
Synergy	The greater the synergy objective, the better the solution

Table 7.10: Solution Quality Criteria

Besides the quality criteria definition for distinguishing solutions, quality criteria is defined to evaluate the solutions regarding the given test set. Table 7.11 shows the name and the description of these criteria.

Name	Description
Size of the space covered	The lesser the non-covered space, the better the solution
Diversity	The greater the number of solutions on the non-dominated front, the better the performance of the algorithm

Table 7.11: Test Set Quality Criteria

The metric *size of the space covered*, presented in [51] and modified in [54], returns a value that describes the space which is not covered by the solutions on the non-dominated front. The value is a fraction of the solution space which is calculated by setting each objective to a utopian value. Thus, the lesser the value of this metric, the better the set of solutions. Figure 7.1 illustrates the concept of this metric for an exemplary optimisation problem with two objectives, X and Y. The red dots show the utopian search space, in setting both objectives to an utopian value. The area in blue shows the covered space of all solutions, marked as blue dots. The grey area shows the space which is not covered by the solutions. The metric *size of the space covered* produces the size of the grey area.

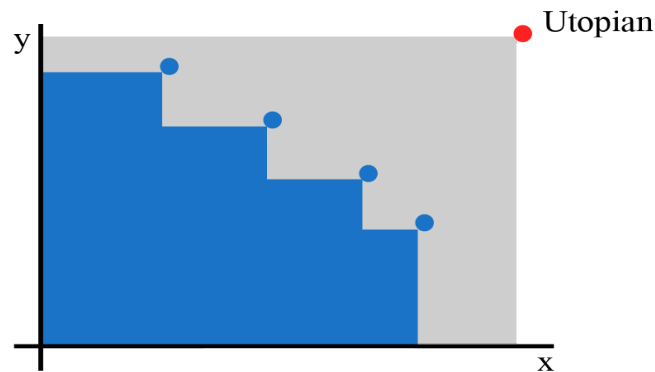


Figure 7.1: Illustration of the Non-Covered-Space Metric

Regarding the criterion *Diversity*, it must be explained that a great number of solutions on the non-dominated front stand for a great diversity of solutions. Diversity is important for increasing the probability of meeting the stakeholders' preferences. Furthermore, the nature of conflicting objectives in multi-objective optimisation is considered by a diverse set of solutions.

### 7.3 Test Runs - Computation and Analysis

The detailed investigation of the presented evolutionary approach to project selection is conducted on a generated set of fifty IT projects. These projects are generated following

the approach presented above. Characteristics and constraints of the test set are presented consequently.

### 7.3.1 Testset

The test set consists of fifty projects. These projects are restricted to having at most 37000 SLOC and at least 1000 SLOC. The maximum duration of a project is restricted to 18 months. The planning horizon is set to three years. The planning horizon is divided into timeframes of the length of a year, resulting in three timeframes. In each timeframe, the available resources are restricted to 500 PM, resulting in a total of 1500 PM for the planning horizon. This value equals 0.6 percent of the resources needed to conduct all projects in the project pool. Each project has an assigned risk value between 0.20 and 0.80.

Since the cost per PM serves as input for the calculation of the potential revenue of a project, this value is set to 5000 Euro per PM. Potential revenue is set to a maximum of 150 percent, and to the minimum of 85 percent of the initial costs.

Listing 7.1 shows an exemplary project structure, and the corresponding generated data. Please note that the test set can be found at <http://www.thomaskremmel.com/mpoems/ppds>.

```

1 <Project PID="39">
2   <SLOC>33928</SLOC>
3   <KSLOC>33</KSLOC>
4   <Phase_Effort >
5     <Inception >3.0</Inception >
6     <Elaboration >12.0</Elaboration >
7     <Construction >38.0</Construction >
8     <DevTotal >50.0</DevTotal >
9     <Transition >6.0</Transition >
10    <Total >59.0</Total >
11  </Phase_Effort >
12  <Phase_Schedule >
13    <Inception >1.56</Inception >
14    <Elaboration >4.67</Elaboration >
15    <Construction >7.78</Construction >
16    <DevTotal >12.44</DevTotal >
17    <Transition >1.56</Transition >
18    <Total >15.56</Total >
19  </Phase_Schedule >
20  <Potential_Revenue >413000</Potential_Revenue >
21  <Month_Effort >
22    <M1 >1.92</M1 >
23    <M2 >2.21</M2 >
24    <M3 >2.57</M3 >
25    <M4 >2.57</M4 >
26    <M5 >2.57</M5 >
27    <M6 >2.57</M6 >
28    <M7 >4.35</M7 >
29    <M8 >4.88</M8 >
30    <M9 >4.88</M9 >
31    <M10 >4.88</M10 >
32    <M11 >4.88</M11 >
33    <M12 >4.88</M12 >
34    <M13 >4.88</M13 >
35    <M14 >4.88</M14 >
36    <M15 >3.86</M15 >
37    <M16 >2.22</M16 >

```

```

38 </Month_Effort>
39 <Starting_Months>0-16</Starting_Months>
40 <Categories>
41 <category1>0</category1>
42 <category2>1</category2>
43 <category3>0</category3>
44 </Categories>
45 <SAV>6.19</SAV>
46 <Risk>0.7</Risk>
47 </Project>

```

Listing 7.1: Exemplary Testset Project

Interdependencies and mutually exclusive projects are restrictions which must be adhered to, in order to create valid portfolios. Figure 7.2 shows the interdependencies used in the test set. These interdependencies are all start-to-finish dependencies. Thus, a predecessor project has to be finished, at least, in the month before the successor project will start. Project 3 is dependent on the projects 43 and 28. Project 43 is in turn dependent on project 12, thus creating an interdependencies chain of length three. The figure shows the dependency from right to left. Thus, if project 21 is selected, project 13 has to be selected for the same portfolio as well. Inversely, project 13 can be part of a valid portfolio, without project 21 being selected for the same portfolio.

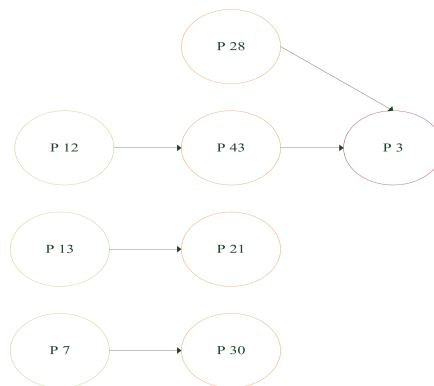


Figure 7.2: Testset - Project Interdependencies

Furthermore, there exist four mutually exclusive projects in the test set. Project 9 is mutually exclusive with project 17, and project 16 is mutually exclusive with project 25. Thus, project 16 and 25 may not be selected for the same portfolio.

**Analysis** To analyse the performance of mPOEMS regarding the optimisation problem presented, the presented approach is used. In the first, step sixty runs with the same configuration are conducted, whereas for each run the seed value is changed. The final SolutionSets of each run are merged, creating a SolutionSet of size, *sbSize* multiplied by the number of runs.

Changing the seed value and the execution of sixty runs is necessary to analyse the mean performance of the algorithm. It lies in the nature of evolutionary algorithms that they have a certain fluctuation range regarding the results, dependent on the seed value, the algorithm implementation details, and the problem to solve.

In the second step, two metrics are calculated to determine the performance of the algorithm regarding the given test set. These two metrics, *Size of the Space Covered* and *Diversity*, are presented in table 7.11. *Size of the Space Covered* is commonly referred to as the Hyper-Volume-Metric (HVM). The HVM is calculated for the SolutionSet, which consists of the merged SolutionSets of the different runs. The *Diversity* metric show the solutions found by the algorithm, which are non-dominated with respect to each other. To calculate the *Diversity* metric, the non-dominated front is calculated out of the merged SolutionSet.

Different configurations have been tested. The best one is presented below, and the results created with this configuration are used to analyse the performance of mPOEMS.

**Used mPOEMS configuration**

- $nIterations = 150$ .
- $sbSize = 500$ .
- $pActive = 75$ .
- $seed$  is changed for each run.

**Used MOEA configuration**

- $nGenerations = 20$ .
- $popSize = 50$ .
- $maxGenes = 20$ .
- $pM = 25$ .
- $pC = 75$ .
- $pBitflip = 15$ .
- $nTournament = 4$ .

**Used Optimisation Problem configuration**

- $nObjectives = 5$ .

- $\text{objective}_1 = 1$ . Maximise potential revenue.
- $\text{objective}_2 = 1$ . Maximise Strategic Alignment Value.
- $\text{objective}_3 = 1$ . Maximise RUDM.
- $\text{objective}_4 = 1$ . Maximise (1 - Risk Deviation).
- $\text{objective}_5 = 1$ . Maximise Sum of Synergy.

This setting results in 150,500 sampled solutions per run. The number of sampled solutions is determined for mPOEMS by calculating  $\text{sbSize} + (\text{nIterations} \cdot \text{nGenerations} \cdot \text{popSize})$ .

The starting population of action sequences is initialised by random. The mandatory projects are selected to start in one of the possible starting months for the project under consideration, whereas the month is selected randomly.

The initial SolutionBase is also created randomly. The starting month for each project is chosen randomly from the available months for each project.

#### Used Project Selection configuration

- $\text{riskRange} = 0.45-0.55$ . Selection pressure is created towards portfolios with a mean risk value of *riskRange*.
- $\text{maxCategoryDeviation} = 0.04$ . The maximum value of the category deviation metric.
- $\text{desiredCategoryPercentage}_1 = 0$ . The desired percentage of projects in a valid portfolio assigned to category one.
- $\text{desiredCategoryPercentage}_2 = 0$ . The desired percentage of projects in a valid portfolio assigned to category two.
- $\text{desiredCategoryPercentage}_3 = 0.30$ . The desired percentage of projects in a valid portfolio assigned to category three.

The  $\text{objective}_4$ , of portfolios with a mean risk value between 0.45 and 0.55, will be set to one. Deviation from this range will be subtracted from one, thus creating selection pressure towards portfolios with a mean risk value of 0.45 till 0.55. The *maxCategoryDeviation* configuration value is set to the restrictive value of 0.04.

The *desiredCategoryPercentage<sub>N</sub>* configuration value specifies the desired number of projects, assigned to a specific category, in a valid portfolio, in percent. If this configuration value is set to zero, the number of projects assigned to category N is ignored. Thus in this test set, the algorithm seeks to create portfolios with a number of 30 percent of the selected projects assigned to category three.



### 7.3.2 Results of mPOEMS

The results obtained with mPOEMS, for the presented test set and the given configuration, are presented in this section. For each of the sixty runs executed, the HVM is calculated. To calculate the HVM, one has to calculate the size of the search space, by setting each objective to a utopian value. For the presented test set with fifty projects, the size of the search space is set to 21E12. Table 7.12 shows the best, the mean, and the standard deviation of the HVM values obtained.

Algorithm	Best	Mean	StDev
mPOEMS	0.217	0.234	0.008

Table 7.12: HVM Results for mPOEMS

The execution of sixty runs with a SolutionBase size of 500 leads to 30000 solutions in the merged SolutionBase file. The non-dominated front, extracted from these 30000 solutions, consists of 2938 solutions.

These results are analysed in chapter 7.3.4, since the most interesting information can be obtained by comparing the mPOEMS results with the results other search algorithms create on the given problem.

These metrics do show the performance of search algorithms regarding multi-objective optimisation. To prove the usefulness of the presented approach to the project selection problem, some other figures are presented in table 7.13. The presented figures are obtained from a single run, and from different solutions. The results in this table are mainly presented to show the range of sampled objectives, and characteristics of created portfolios.

Objective	MAX	MIN	MEAN
Potential Revenue	9520398	4910899	7777545
SAV	5.32	3.90	4.86
RUDM	0.99	0.15	0.67
Risk	0.46	0.40	0.44
Positive Synergy	213100	0	107901
Negative Synergy	110250	0	30500.6
‡ Selected Projects	33	19	26.55
Category Three	0.4	0.2	0.29

Table 7.13: Analysis - Various Metrics

The table 7.13 presented above shows some interesting figures out of a single test run.

With these figures the range of objective values found by the algorithm are presented, whereas some interesting values are explained in detail.

In the set of five hundred created portfolios the maximum value found for the potential revenue objective is 9520398. The used test set with fifty projects has a summed potential revenue of 15328198. The minimum potential revenue for a portfolio is 4910899. The value of the RUDM shows the maximum value of 0.99, which means that portfolios have been created, which use almost all available resources in each timeframe. On average, the algorithm created portfolios with a resource usage of 0.67. Furthermore, the number of maximum projects selected is 33, and the minimum is 19. On average 26.55 projects have been selected for a portfolio.

The synergy objective is divided into the two parts, negative and positive synergy, which contribute their values to calculate the synergy objective. It is interesting that the algorithm found the combination of projects which leads to the highest possible positive synergy, which is 213100. The mean value of the negative synergy is significantly lower than the mean value of the positive synergy, whereas the maximum synergy values are for both parts almost equal, 206350 for the negative synergy part, and 213100 for the positive synergy part. This led to the conclusion that the algorithm does prefer combinations of projects which lead to higher overall synergy, and thus demonstrate the effectiveness of the combined synergy objective.

Note also the mean risk value of 0.44. This is interesting since the setting preferred portfolios with a mean risk value of 0.45 to 0.55. Probably the reason for this behaviour lies within the test data. The mean risk value for all fifty projects is 0.42. Thus, it is probably difficult to attain risk values which are about 0.50 on average. Out of this view, a mean risk value of 0.44 does seem reasonable.

Regarding the SAV objective, the algorithm created portfolios with a mean value of 4.86, which is significantly higher than the mean SAV value of the whole test set, which is 3.95.

Especially interesting is the mean value of projects assigned to category three. The desired number of projects assigned to category three was 0.30. The algorithm created on average portfolios with 0.29 percent of the projects assigned to category three.

These results prove that the presented approach does create valid portfolios, with characteristics which do follow preferences which have been set in advance. The framework is highly flexible. Thus, preferences and restrictions could be easily restricted, relaxed or completely removed. It is shown that the algorithm produces very good results, and does create solutions with a very broad range of objectives. A broad range of objectives is important for increasing the probability of meeting the preferences of decision makers. Because of these characteristics, the approach has great potential for supporting decision

makers in the process of selecting projects.

In order to understand how good the results are, regarding multi-objective optimisation, mPOEMS has to be compared with other search algorithms. Therefore, a comparison of the results with NSGA-2 and SPEA2 is presented in the next section.

### 7.3.3 Results using PISA

The PISA framework is used to conduct comparison of the presented optimisation approach, which uses mPOEMS, with another evolutionary search algorithm. PISA is a platform and programming language independent interface for search algorithms, presented in [55]. The use of PISA ensures easy, fast and reliable comparison of different optimisation algorithms on various problems or benchmarks. With little programming effort one can create the problem-specific part of an optimisation problem, and combine it with arbitrary, ready-to-use, pre-compiled and very complex optimisation search algorithms.

Figure 7.3 illustrates the basic working principle of PISA. The left-hand side illustrates the optimising algorithms like SPEA-2 and NSGA-2, whereas the right-hand side presents the optimising problems. Please note that the selectors can be arbitrarily combined with the variators, and vice versa. The optimising algorithms are called selectors, since most research in multi-objective optimisation was conducted in the way how solutions are selected [55]. The use of textfiles for the communication between the modules ensures platform and programming language independence.

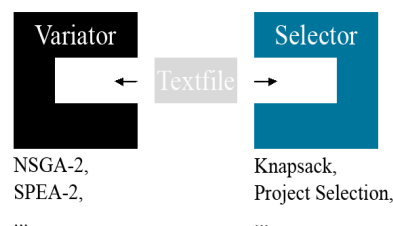


Figure 7.3: PISA - Working Principle

Several selectors and variators, as well as detailed documentation can be found at the website of the project <http://www.tik.ee.ethz.ch/sop/pisa/>. To conduct a comparison of the JAVA mPOEMS approach to the project selection problem, a JAVA prototype for the variator side, accompanied with very helpful information, was provided by Tamara Ulrich of the ETH Systems Optimization Group of Zürich. This prototype was used to adapt the problem-dependent part of the JAVA mPOEMS approach to work with PISA. Due to a clear, problem-independent structure of the JAVA PISA prototype, most of the problem-dependent source code, of the JAVA mPOEMS approach to the project selection problem,

was only copied into the PISA prototype, with slight modifications. These modifications were mostly located in the variator operators of PISA. Since mPOEMS uses so-called actions to modify the solution representation, adequate variation operators have to be found to ensure proper comparison.

*changeMonth* and *switchOnOff* are the actions used in the mPOEMS approach. Variation operators may be implemented as mutation operators. To implement the logic of the mPOEMS actions, the mutation operation is taken to either simulate the *changeMonth* or the *switchOnOff* action, whereas each operation is chosen with a probability of fifty percent. Each call of the mutate method results in the traversing of the solution vector, and each project in the solution vector is mutated with a probability, specified in the configuration value *bitflip\_probability*. The best results are obtained with a two-point crossover. One-point and uniform crossover led to slightly worse results.

PISA provides the user with various configuration values, grouped into three different domains, which are presented below.

#### **Selector configuration**

- *maximum\_generations* defines the number of generations.
- *recombination\_probability* sets the probability of recombination/crossover.
- *mutation\_probability* sets the probability of mutation.
- *bitflip\_probability* sets the probability to flip one bit. In the case of project selection it is the probability to mutate the setting of a project in the solution vector.
- *seed* defines the seed configuration value for the random number generator.

#### **Variator configuration**

- *tournament* defines the number of candidates, which take part in the Tournament Selection.
- *seed* defines the seed configuration value for the random number generator.

#### **PISA configuration**

- *alpha* defines the number of individuals in the initial population.
- *mu* defines the number of parents which are selected by the selector.
- *lambda* defines the number of offspring which is generated by the variator.
- *dim* defines the number of objectives.

### 7.3.4 Comparison NSGA-2, SPEA-2, and mPOEMS

The search for the best configuration for NSGA-2 and SPEA-2 led to the conclusion that these two search algorithms, are not very sensitive to different settings, regarding the optimisation problem at hand. Nevertheless, the configuration is used which creates the best solutions. The configuration values for both algorithms are presented below. The used configuration values differ only in the setting of the `bitflip_probability`. For NSGA-2, the `bitflip_probability` is set to 0.04, whereas the setting for SPEA-2 is 0.02.

#### Selector configuration

- *maximum\_generations* = 600.
- *recombination\_probability* = 0.7.
- *mutation\_probability* = 1.
- *bitflip\_probability* = 0.02 (SPEA-2) and 0.04 (NSGA-2).
- *seed* is changed for each run.

#### Variator configuration

- *tournament* = 2.
- *seed* is changed for each run. Is always set to the same seed value, which is used for the selector.

#### PISA configuration

- *alpha* = 500.
- *mu* = 250.
- *lambda* = 250.
- *dim* = 5.

This setting results in 150,000 sampled solutions per run. The number of sampled solutions is determined for NSGA-2 and SPEA-2 by calculating  $\lambda \cdot \text{maximum\_generations}$ . A similar number of sampled solutions is important as to ensure a fair comparison.

The same approach to analyse the results is used as in the analysis of the mPOEMS results. Thus, sixty runs are conducted, which lead to a set of 30,000 solutions. Out of these 30,000 solutions, the non-dominated front is extracted, and the HVM is calculated.

Algorithm	Best	Mean	StDev
SPEA-2	0.217	0.230	0.015
NSGA-2	0.223	0.233	0.004
mPOEMS	0.217	0.234	0.008

Table 7.14: HVM Results for SPEA-2, NSGA-2 and mPOEMS

Table 7.14 shows the HVM results for NSGA-2, SPEA-2 and mPOEMS.

The HVM results show that the solutions created by SPEA-2 and NSGA-2 cover a greater part of the solution space than does mPOEMS. While NSGA-2 create just slightly better HVM results on average, solutions found by SPEA-2 lead to a mean HVM which is 0.004 percent better than the results found by mPOEMS. On the other hand, mPOEMS and SPEA-2 find the solutions which lead to the best HVM value found. The results for the standard deviation show that NSGA-2 has the lowest range of fluctuation in the results regarding the HVM value.

Since the goal of multi-objective optimisation is to find on the one hand a set of non-dominated solutions which do cover a part of the search space, which is as wide as possible, and on the other hand, that which is as close as possible to the Pareto optimal front, another metric has to be used to judge the performance of these algorithms. For this purpose, the coverage metric is used. This metric shows how many solutions out of set A are dominated by solutions from set B, and vice versa. The lesser the number of solutions that are dominated by solutions from another algorithm, the better the algorithm under consideration.

To calculate the coverage metric, the non-dominated front of the found solutions has to be calculated. The sizes of the non-dominated front for the algorithms under consideration are presented in table 7.15.

Algorithm	Size of the Non-Dominated-Front
SPEA-2	2833
NSGA-2	2491
mPOEMS	2938

Table 7.15: Size of the Non-Dominated Front

Regarding the size of the non-dominated front, mPOEMS does show the best performance, with 2938 non-dominated solutions out of 30,000. The non-dominated fronts are used to calculate the coverage metric. The results of the coverage metric are presented in table 7.16. Numbers in each cell show the fraction of solutions obtained by the algorithm in the given column, which are dominated by solutions found by the algorithm in the given

row.

Algorithm	SPEA-2	NSGA-2	mPOEMS
SPEA-2	-	0.6315	0.3479
NSGA-2	0.1980	-	0.1773
mPOEMS	0.4384	0.6210	-

Table 7.16: Coverage Results for SPEA-2, NSGA-2 and mPOEMS

Coverage results show that SPEA-2 and mPOEMS clearly outperform NSGA-2. 63.15 percent of the solutions found by NSGA-2 are dominated by solutions found by SPEA-2. mPOEMS dominates 62.10 percent of NSGA-2 Solutions.

The comparison of SPEA-2 and mPOEMS show that mPOEMS dominates 43.84 percent of solutions found by SPEA-2, and vice versa SPEA-2 solutions dominate 34.79 percent of the mPOEMS solutions. Thus, mPOEMS does show clearly the best performance regarding the coverage metric.

Summarised, mPOEMS does show slightly worse mean results regarding the HVM, whereas it found, as well like SPEA-2, the best HVM result. Regarding the coverage metric, mPOEMS clearly outperforms NSGA-2 and SPEA-2.

The reason that mPOEMS performs best regarding the coverage metric, while having a slightly worse HVM value, is found in the interval focus of the optimisation algorithms. As one may see in the tables 7.17, 7.18, and 7.19, mPOEMS focuses on a narrower interval than SPEA-2 and NSGA-2, whereas SPEA-2 and NSGA-2 sample a wider range of objectives.

Objective	MAX	MIN	MEAN
Potential Revenue	9631398	4654449	7796719
SAV	5.36	3.73	4.85
RUDM	0.99	0.11	0.68
Risk	1	0.95	0.99
Synergy	189750	-61700	83874.93

Table 7.17: Interval Results for mPOEMS

In calculating the max-min ratio of the objectives, the fact that SPEA-2 and NSGA-2 sample a wider range of objectives is made obvious. The max-min ratio is calculated by subtracting the min value from the objectives max value, then dividing the resulting value by the min value, and multiplying it by one hundred to get the value in percent. Table 7.20 shows the results of the calculation of this max-min ratio. The lower the value of the max-min ratio, the narrower is the sampled interval of the solutions. The lowest values are

Objective	MAX	MIN	MEAN
Potential Revenue	9707549	3678350	7560797
SAV	5.4	3.60	4.88
RUDM	0.99	0.06	0.64
Risk	1	0.93	0.99
Synergy	189750	-127150	61681.15

Table 7.18: Interval Results for SPEA-2

Objective	MAX	MIN	MEAN
Potential Revenue	9690199	3895400	7434718
SAV	5.4	3.49	4.87
RUDM	0.99	0.07	0.60
Risk	1	0.92	0.99
Synergy	189750	-146650	60782.22

Table 7.19: Interval Results for NSGA-2

all coloured in red, and it shows that mPOEMS does sample the narrowest interval in all five objectives. Please note that for the calculation of the max-min ratio for the synergy, 160,000 were added to each minimum and maximum value. This was done to create a positive ratio value. Whereas the results change a bit, the general tendency which show that mPOEMS focuses on a narrower interval is not influenced.

The HVM rewards the behaviour of having extreme values in some objectives, as it is shown in the solution sampling of NSGA-2 and SPEA-2. Extreme values in one or more objectives often lead to very low values in the non-extreme objectives. Since the goal of multi-objective optimisation is to optimise all available objectives towards their optimum, it is not desirable to have extreme values while other objectives do show very bad results. Furthermore, extreme values have a higher probability that they are not practicable.

Thus, mPOEMS is able to pursue the main goal of multi-objective optimisation, which is to find the optimum in all objectives and tune them together, more than SPEA-2 and NSGA-2. mPOEMS tuned better its objectives together, and is, from a practical point of view, the best optimisation algorithm, out of the compared ones, for the problem under consideration.

After presenting the general applicability of mPOEMS to the project selection problem as well as and its superiority over two state-of-the-art optimisation algorithms with respect to two out of three multi-criteria optimisation metrics, the next chapter presents



Algorithm	Max-Min Ratio in Percent		
	SPEA-2	NSGA-2	mPOEMS
Potential Revenue	164	149	107
SAV	50	55	44
RUDM	1548	1254	827
Risk	8	8	6
Synergy	965	2520	256

Table 7.20: Max - Min Ratio for SPEA-2, NSGA-2 and mPOEMS

an Interactive Visualisation & Discussion concept for the selection of one portfolio out of the pareto-optimal front.

## 8 Interactive Visualisation & Discussion

This chapter presents a group decision process for the selection of one portfolio out of the pareto-optimal front. Suitable visualisations and data exploration techniques are part of this decision process. The core of the presented group decision process are decision model, decision rules and preference functions. It is shown how individual preferences could be inserted into the presented visualisations, encoded as colour and size. This encoding and the presented data exploration techniques enable the user to playfully explore the solution space and ease the search for consent by selecting solutions encoded with specific colour and specific size.

The research issues eight to ten are dealt with in this chapter. It shows the process of selecting one portfolio out of the pareto optimal front could be adapted to group decisions. Suitable visualisation and data exploration techniques are presented, and a method is presented to insert individual preferences into the decision process.

The next section presents the group decision process and shows some visualisations and data exploration techniques used.

### 8.1 Group Decision Process

Since a project portfolio is commonly chosen by more than one person, this process is especially designed to be applicable to a group of decision makers. The core of the group decision process is a decision model, including decision rules and preference functions, which reduce the evaluation of an alternative to an analytical operation [28].

#### 8.1.1 Preference Function

The result of a preference function is a subjective order of the alternatives, whereas the preference function must strictly adhere to the order- and transitivity axiom. The order axiom assures that it is possible to explicitly compare alternatives. Thus, a preference function has to provide the decision maker with the ability to indicate, from the decision maker's subjective view, whether an alternative is considered as better, worse, or the same,

than another alternative. Furthermore, a preference function has to assure that if a decision maker indicates that alternative A is preferred over alternative B, and alternative B is in turn preferred over alternative C, it has to be true that alternative A is also preferred to alternative C. This interrelation is called the transitivity axiom [28].

Of special importance is the ability of a preference function to indicate the intensity of a preference of an alternative over another alternative. As input to the preference function serves the results which one think an alternative will cause [28]. In the case of the evolutionary approach to project selection, the main input into the preference function are the objectives that are either maximised or minimised in the process of creating valid portfolios. Furthermore, decision rules will be introduced, which enable decision makers to reflect their point of view in the preference value. These rules will either completely remove alternatives from the subjective set of solutions, or re-calculate the preference value and add or remove a certain value.

In order to demonstrate the creation of the proposed preference function, a simplified and numerically restricted example of a set of portfolio alternatives is presented. These solutions, presented in table 8.1, are used to show the steps which have to be conducted in order to create a preference value for each solution, using the proposed preference function.

Nr.	Potential Revenue	SAV	RUDM	Risk	Synergy
1	6700000	5.2	.43	.97	-54000
2	7100000	3.16	.53	.81	76000
3	9300000	4.08	.95	1.	14200
4	9100000	5.02	.97	.75	-120000
5	4300000	6.98	.54	.96	400100
6	5600000	5.2	.76	.99	54000

Table 8.1: Simplified Set of Six Portfolios with Five Objectives

Two steps have to be conducted in order to create a subjective preference value. The first step is the normalisation of the objective values of the presented portfolios. The normalised values are presented in table 8.2, and are calculated following the presented equation,

$$\frac{o_{i,s} - \text{Min}(o_i)}{\text{Max}(o_i) - \text{Min}(o_i)} \quad (8.1)$$

where  $o_i$  is the value of *objective<sub>i</sub>* of *solution<sub>s</sub>*,  $\text{Min}(o_i)$  is the minimum value of *objective<sub>i</sub>*, and  $\text{Max}(o_i)$  is the maximum value of *objective<sub>i</sub>*.

Nr.	Potential Revenue	SAV	RUDM	Risk	Synergy
1	0.30	0.53	0.00	0.88	0.13
2	0.41	0.00	0.19	0.24	0.38
3	1.00	0.24	0.96	1.00	0.26
4	0.95	0.49	1.00	0.00	0.00
5	0.46	1.00	0.76	0.84	1.00
6	0.00	0.53	0.61	0.96	0.33

Table 8.2: Normalised Objectives of a Simplified Set of Six Portfolios

In the next step, the objectives are weighted, regarding the preferences of a decision maker or a group of decision makers. In the proposed approach, the decision maker may allocate a certain number of points to the objectives. In the example presented, the total of points to allocate is restricted to fifteen. Thereby a minimum of zero and a maximum of fifteen may be allocated to a single objective. Table 8.3 shows an exemplary distribution of allocated points for two different decision makers.

Decision Maker	Potential Revenue	SAV	RUDM	Risk	Synergy
1	7	4	4	0	0
2	2	5	3	3	2

Table 8.3: Allocated Points for Two Decision Makers

The weighting of the solutions multiplied with these values results in preference values, presented in table 8.4.

Decision Maker	S 1	S 2	S 3	S 4	S 5	S 6
1	4.22	3.63	11.80	12.61	10.26	4.56
2	6.15	2.87	9.60	7.35	12.72	8.02

Table 8.4: Weighted Solutions For Two Decision Makers

These preference values obey the order- and transitivity axiom. Furthermore, the intensity of how much one alternative is preferred over another is given through the numerical distance of two preference values.

### 8.1.2 Decision Rules

Core value of the decision model is the preference values calculated with the preference function presented above. In order to be able to reflect various subjective opinions, de-

sires and knowledge, so-called decision rules are introduced. Some decision rules for the project portfolio selection problem are presented here, whereas the number of decision rules is theoretically not restricted, and is highly dependent on the environment where this group decision process is adopted.

Decision rules manipulate the preference values in a way that the newly calculated preference values express the subjective point of view of a decision maker. Therefore, a decision rule will either add or remove a certain value to the preference value. Three different decision rules are specified. These are called *must*, *must not*, and *should* decision rules.

**must decision rules** are so-called knock-out rules, since the preference value of portfolios which do not fulfil such a criterion will be set to zero. Knock-out rules are basically created to exclude portfolios from the pareto-optimal front, which do not meet the preferences of decision makers.

The following listing shows some possible *must decision rules*:

- Project *XY* has to be included in the portfolio
- A portfolio must have more than  $n$  projects included
- Objective *XY* has to be above value  $v$

**must not decision rules** are also so called knock-out rules. Put simply, they are the inversion of the *must decision rules*.

The following listing show some possible *must not decision rules*:

- Project *XY* must not be included in the portfolio
- A portfolio must not have more than  $n$  projects included
- A certain combination of projects must not exist in a portfolio

**should decision rules** add or remove a certain value, based on whether a certain aspect of the decision maker's subjective view is supported by an alternative or not. To illustrate the use of such decision rules, an example is given, showing the subjective preference of a decision maker regarding the resource usage in portfolio optimisation. Let's assume that a decision maker prefers portfolios with an overall resource usage of eighty to eighty-five percent, in order to ensure a high resource usage, and to have some space for unpredictable circumstances in the future. Furthermore, the decision maker does not want to select portfolios with a resource usage less than seventy and more than ninety-five

percent. The first step in applying this decision rule is to calculate the preference value as presented above. The calculated preference value is now adjusted, based on the variables influencing the *should decision rules*. In our example, the only variable is the resource usage metric. For each portfolio with a resource usage between eighty and eighty-five percent, the preference value is not adjusted. Portfolios, which do not have a resource usage within this range, are less attractive in the view of the decision maker. To illustrate this fact, the preference value of such portfolios is reduced. This could be done in different ways. For the presented example, an approach, where the weighting of the resource usage objective is adjusted, is suitable.

Since the decision maker prefers portfolios with a resource usage of at least seventy, and at most ninety-five percent, portfolios with a resource usage between seventy and eighty percent, as well as between eighty-five and ninety-five percent, will have their weighting value adjusted. The weighting value of the resource usage objective, for portfolios with a resource usage below seventy and above ninety-five percent, will be set to zero. The adjusted weighting values are calculated by removing a tenth part of the original weighting value for each percent which is below or above the desired percentage. Thus, a portfolio with 76.5 percent resource usage and a weighting of five for the resource usage objective will have the weighting value diminished to the value three.

Following this approach, the weighting value reflects, on the one hand, the relative importance of an objective, and on the other hand, the intensity of adherence to different decision rules.

The preference value as the major output of the decision model serves as input for the visualisation part of the group decision process.

## 8.2 Visualisation

This chapter shows how visualisations may be used to present, analyse, and explore the non-dominated front of project portfolios. A brush- and linking technique is presented, which supports decision makers with different subjective views and therefore different preference values, enabling them to agree on the selection of the portfolio. The commercially available visualisation tool *Tableau* is used to create the graphics and to explore the data. *Tableau* can be downloaded at the website <http://www.tableausoftware.com/>.

"Not the complication of the simple; rather the task of the designer is to give visual access to the subtle and the difficult - that is, the revelation of the complex."

This quotation of Tufte, from the book, *The Visual Display of Quantitative Information* [46], was not only selected because of its elegance, but especially because it does a great job of introducing the problem area of the visual presentation of complex data. It states that the main goal of visually presenting information, is to help the viewers understand the data, reveal complex interrelations, and gain insight. This is done by utilising one of the most powerful, and at the same time, simplest methods to analyse and communicate statistical information - data graphics [46].

The human's three dimensional perception requires sophisticated visualisation and interacting techniques, to clearly present information that has more than three dimensions. Parallel coordinates [20], Treemaps [43] and Stardiates [30] [29], are so-called sophisticated visualisation techniques. The approach presented to visualise portfolio data will use standard techniques like x-y plots and bar charts, in combination with sophisticated interacting techniques like brushing and linking. Further research should be done to test the usefulness of stardiates for the portfolio selection problem. Because of its potential to create unique patterns, and to provide a convenient overview of n-dimensional data, stardiates could be especially suitable to graphically present the objectives of portfolios in an overview.

Brushing and linking are data exploration techniques. The main advantage of visual data exploration techniques is that the user playfully explores the data and is directly involved in the data mining process [22]. These exploration techniques are the main techniques used in the presented group decision approach, since it provides the user with the ability to link different views on the data, and it is an easy way to visually search for consent in individual preferences.

The concept of linking is based on the theorem that it is usually more effective to create graphics which focus on a certain aspect of the data, which are easy to understand and are simple in construction. The data as a whole is then integrated into a cohesive image by way of linking these single pictures, and therefore combining the information contained in each view [7]. Linking graphics enables the user to view only the data for a subset of the whole data set, and view various aspects of the data simultaneously.

Brushing is a method which empowers the user with the ability to highlight, select or delete a subset of elements [48]. The region which is marked by this method is called a *brush*. Brushing enables the decision maker to manually set aspiration levels and apply filters in an easy and intuitive way, based on his visual perception

In order to illustrate the preference values of the decision makers in a way that assures fast and reliable visual processing, retinal properties are utilised. Retinal properties were given their name, because the retina of the eye is sensitive to them [8]. Colour, texture, shape, size and position are some of them. The human visual system can process pictures

and relationships of such retinal properties much faster than we can scan and understand textual descriptions [44]. Such fast processing properties greatly facilitate the search for consent in individual preferences. Colour encoding especially does a great job in displaying ordinal, continuous values. This is because of the colours' inherent fineness of distinction in value, saturation and hue [47].

To show the potential of this approach, these visualisation techniques are presented within an example of five different decision makers. Out of two hundred efficient portfolios one portfolio should be chosen. The example shows that within a few steps an agreement can be found, based on the individual preferences of the decision makers. Table 8.5 shows the weighting of the decision makers.

Decision Maker	Potential Revenue	SAV	RUDM	Risk	Synergy
1	7	4	4	0	0
2	2	5	3	3	2
3	0	16	0	0	0
4	2	3	4	4	3
5	10	3	0	0	3

Table 8.5: Allocated Points for Five Decision Makers

The resulting preference values are presented and used in the illustrations as colours in different hues, as different sizes of bars and circles, and in filters. Figure 8.1 shows a potential entry dashboard into the decision process. This dashboard consists out of two separate views. The view located at the top shows in the x-variable the *Strategic Alignment Value* of the portfolio, whereas the x-variable presents the calculated *Potential Revenue*. Furthermore, the hue of the blue colour represents the preference values of the decision maker number one. The size of the circles represents the preference values of the decision maker number two. Thus in the search process for consensus in the preference values of these two decision makers, one has to search for big, dark blue circles.

The view, located on the bottom of figure 8.1, shows the preferences of decision maker three in the size of the bars of the bar chart, and the preferences of decision maker four are colour coded. Thus, big, dark-orange bars, show high agreement on the preference of these two decision makers. Furthermore, the preferences of decision maker five are added as a dynamic filter to ensure high agreement with the fifth decision maker as well.

First of all, the decision makers will clearly see that there is a negative correlation between potential revenue and the *Strategic Alignment Value*. This is probably because for a high potential revenue, projects have to be chosen for a portfolio, which do not have



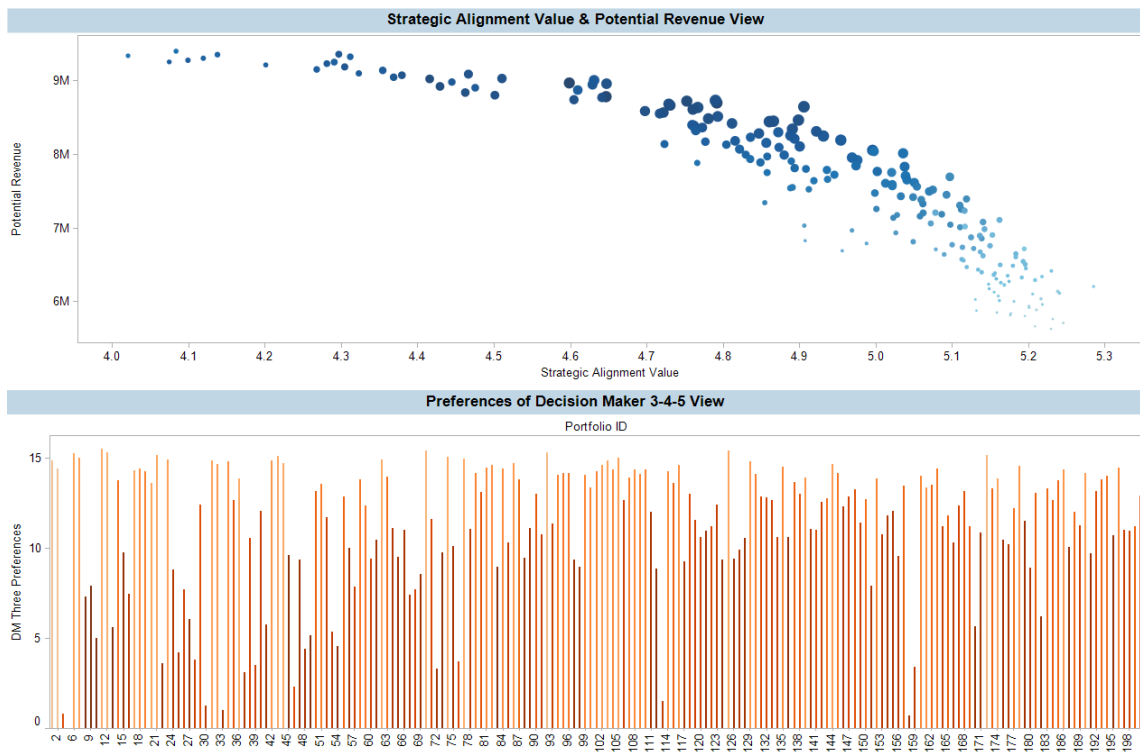


Figure 8.1: Visualisation - Entry Dashboard

a high *Strategic Alignment Value*.

At this point, two methods are possible to extract one portfolio from the two hundred portfolios. It is suggested that each method should be played through at least one time. The results will be kept, resulting in a set of selected portfolios. To choose one portfolio of this small set, decision makers could add more views to see more details of the portfolios, or they could calculate the variance of the decision makers' preference for the portfolios, and choose the one with the smallest variance, since this solution shows the greatest consent found with this approach.

The first method starts in the *Strategic Alignment Value & Potential Revenue* view, shown in figure 8.2. In the first step, the decision makers mark the biggest and darkest blue dots they find, visually creating a brush. With the command *Keep Only*, the view is updated, and all unselected solutions are removed. The resulting view is presented in figure 8.3. Note that the scales of the x- and y-axis, the colours, and size of the dots respectively, are adjusted to the visible dots. Thus, the resulting view shows the new relations, ensuring the further selection of solutions with the data exploration technique brush and exclude.

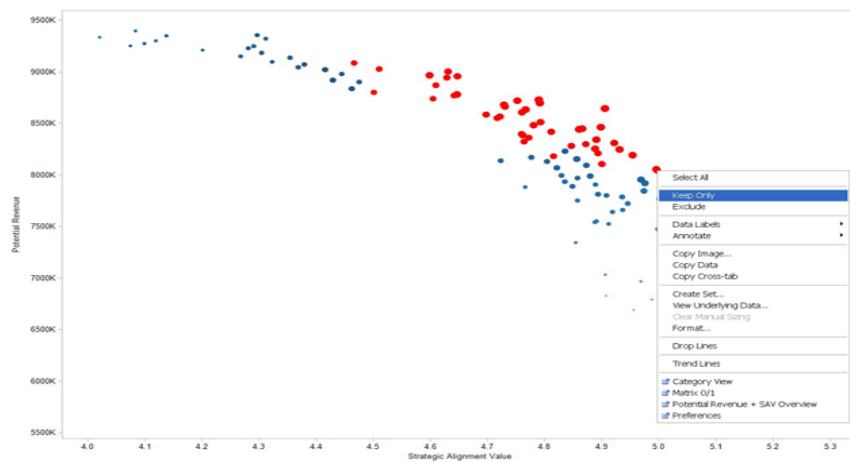


Figure 8.2: Visualisation - Brush and Exclude - View One

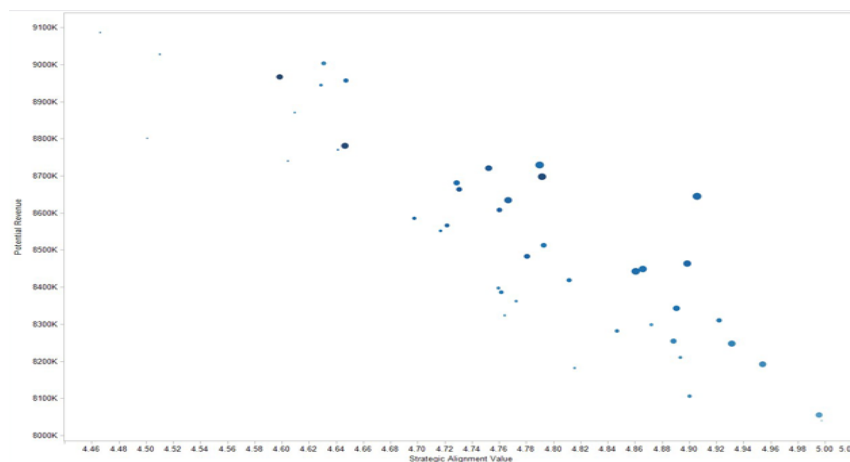


Figure 8.3: Visualisation - Brush and Exclude - View Two

Figure 8.4 and figure 8.5 show the continued selection of solutions. The exclusion of solutions continues until one or more solutions is visible, which reveals the highest agreement in the preferences, encoded in size and saturation of the solutions.

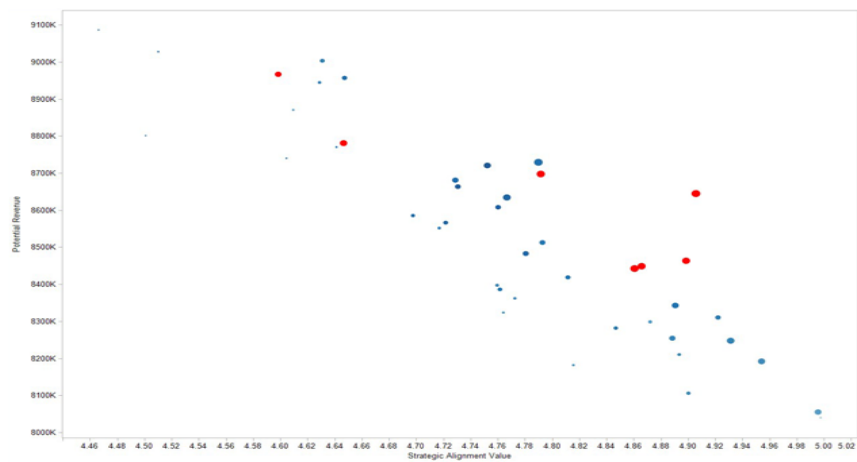


Figure 8.4: Visualisation - Brush and Exclude - View Three

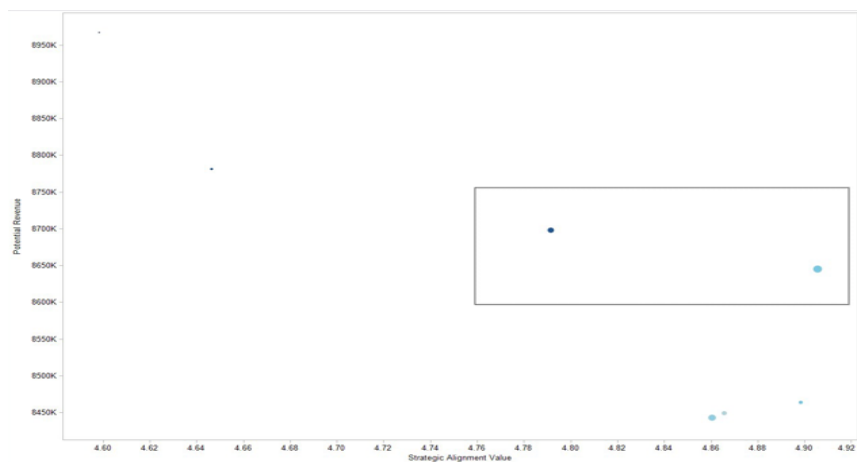


Figure 8.5: Visualisation - Brush and Exclude - View Four

In view five, presented in figure 8.6, the solutions with the greatest agreement regarding the preferences, are marked, in order to remember them for further selection.

View six, presented in figure 8.7, shows the found solutions in the overview view.

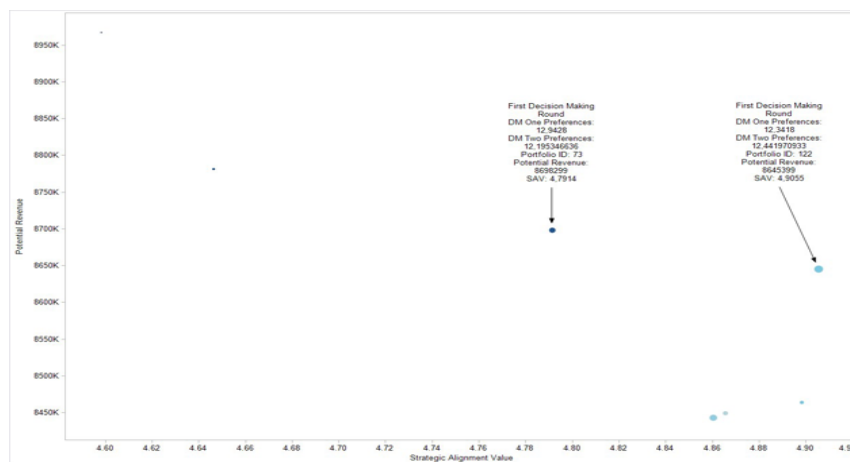


Figure 8.6: Visualisation - Brush and Exclude - View Five

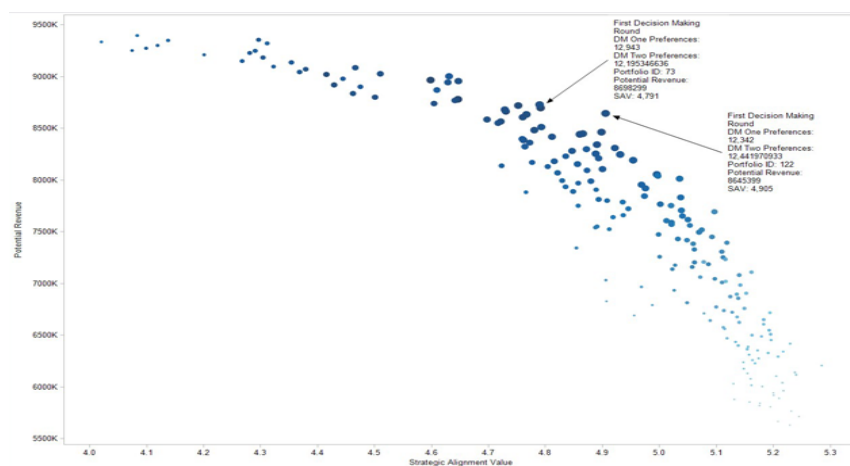


Figure 8.7: Visualisation - Brush and Exclude - View Six

In the second approach, dynamic filters are used for the selection of portfolios, based on the preferences of the decision makers. This approach shows how three preferences could be matched, easily and fast. Figure 8.8 shows the *Preferences* view of decision maker three, four and five. The size of the bars represents the preference values of decision maker three. The bigger the bar, the greater the preference value for the solution. Preferences of decision maker four are encoded with colour. Thus, dark orange/brown bars signify great agreement with the preference values of decision maker four. Preferences of decision maker five could be encoded as width of the bars. In order to not visually overload the decision makers, these preferences are only illustrated, in the upper right corner, in the dynamic filter. Furthermore, dynamic filters for decision maker three and four are added as well.

In the first step of this method, the slider of the filter is adjusted for the decision makers five preferences. Thus, the first selection determines all solutions from the view which

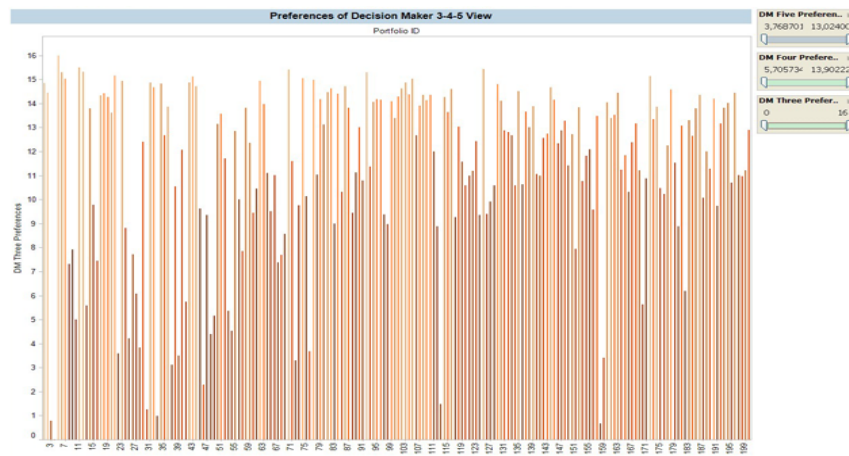


Figure 8.8: Visualisation - Dynamic Filters - View One

do have a decision maker five preference value, below 10.59. The results are presented in figure 8.9. The adjustment of this filter results in a change of the colour of the other two filters. The green part of the filters shows for which values solutions can be found from the filtered solution set. Therefore the decision makers only have to adjust the other two filters, as they attempt to achieve a good balance between the three filters.

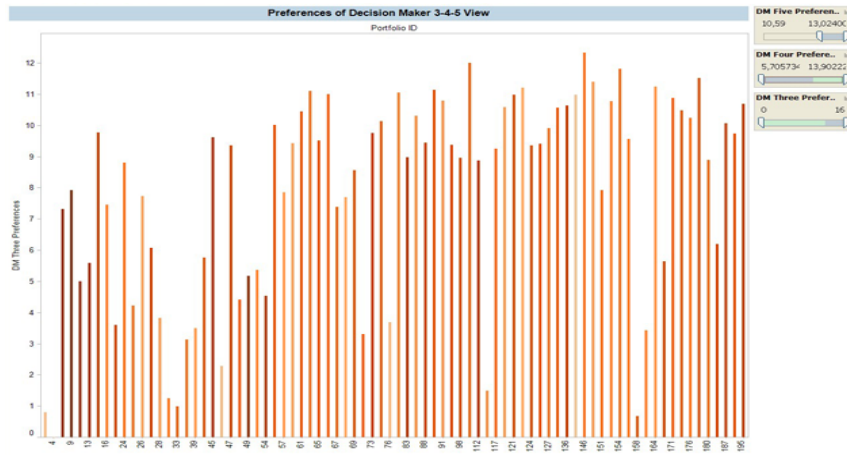


Figure 8.9: Visualisation - Dynamic Filters - View Two

Figure 8.10 shows the resulting portfolios when all filters are set to the highest possible balance. The results are marked for further selection.

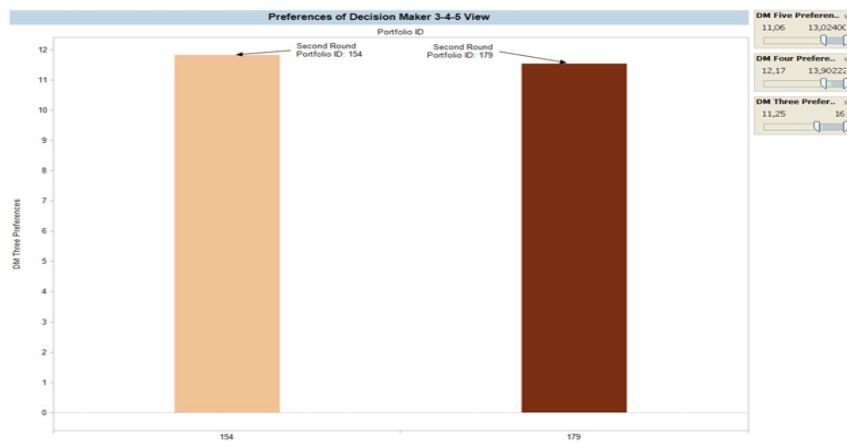


Figure 8.10: Visualisation - Dynamic Filters - View Three

The overview, presented in figure 8.11, shows the selected and marked solutions found in the two methods presented, coloured in red. These four solutions are shown in figure 8.12. This view of the selected solutions is the starting point for the final selection of one portfolio. The final selection can be conducted by calculating the variance of the five preference values for each portfolio. The lowest variance shows the portfolio with the greatest balance, regarding the preferences off all decision makers. Furthermore, the selection of solutions based on the *brush and exclude*, as well as from the *dynamic filters*, approach, ensure high consent, regarding all decision maker preferences.

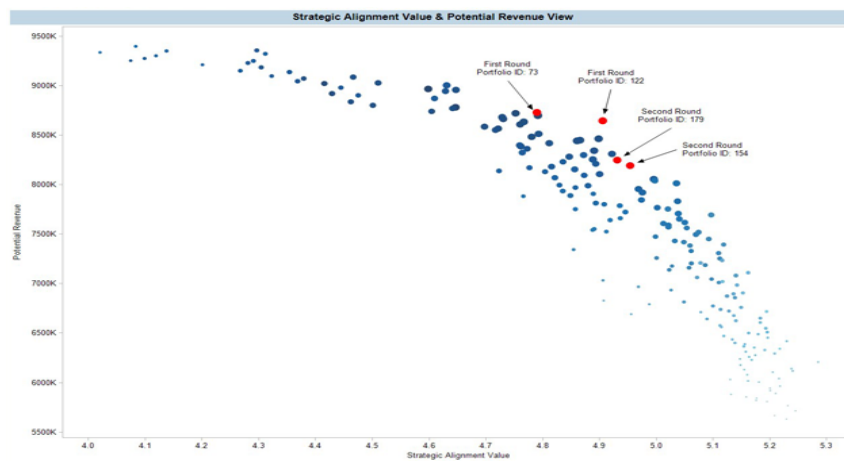


Figure 8.11: Visualisation - Results - Overview

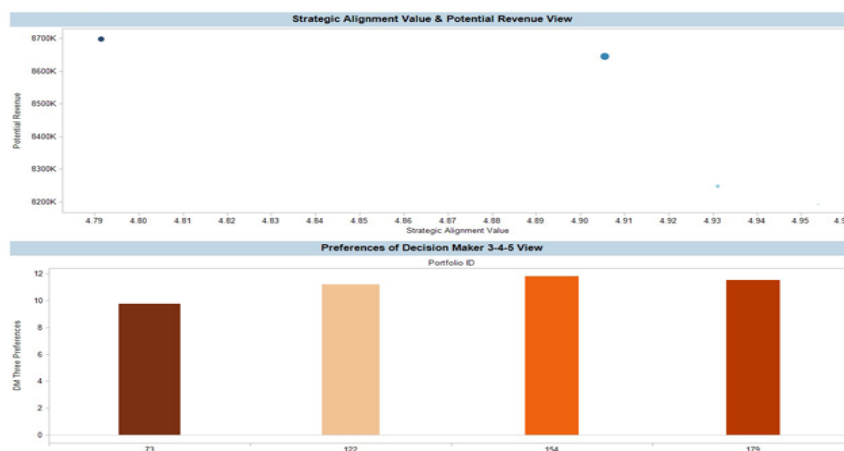


Figure 8.12: Visualisation - Results - Selected

Besides the final selection based on the variance, detail views could support the decision makers in their final decision. Different parts of the data could be viewed by linking the overview to the figures listed below. For example, figure 8.13 can be used to see the synergy values of a portfolio, and figure 8.14 can be used to specify portfolios, which do not have enough projects assigned to a specific category. Furthermore, figure 8.15 presents to the decision maker which projects are included in the portfolios under consideration.

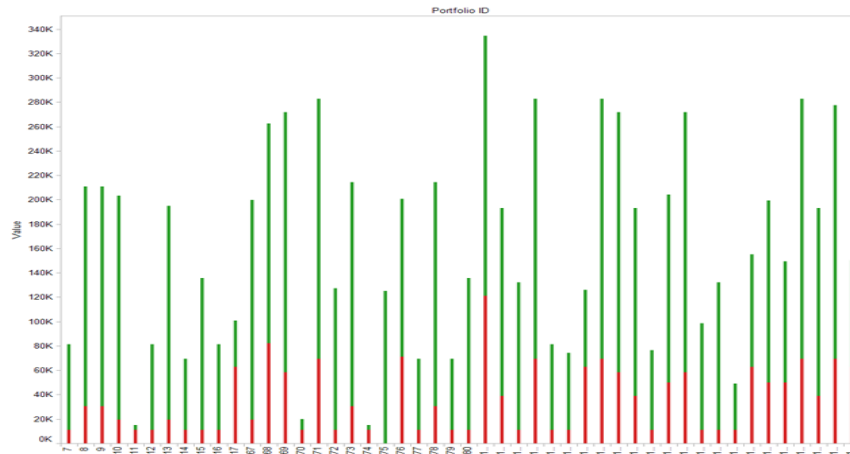


Figure 8.13: Visualisation - Details - Synergy

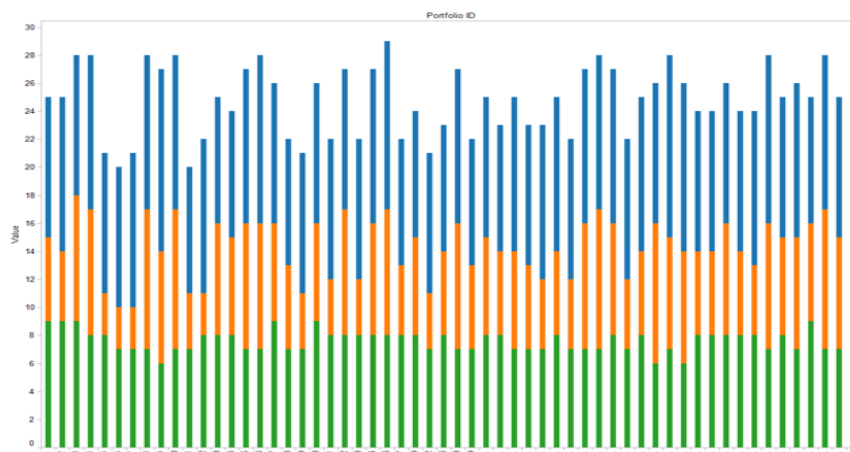


Figure 8.14: Visualisation - Details - Category



Using the presented group decision process with its preference functions and decision rules, together with the presented visualisation and data exploration techniques, I believe that a board of decision makers is given an easy-to-use, powerful framework to facilitate the difficult search for a portfolio candidate, which suits all needs and preferences.

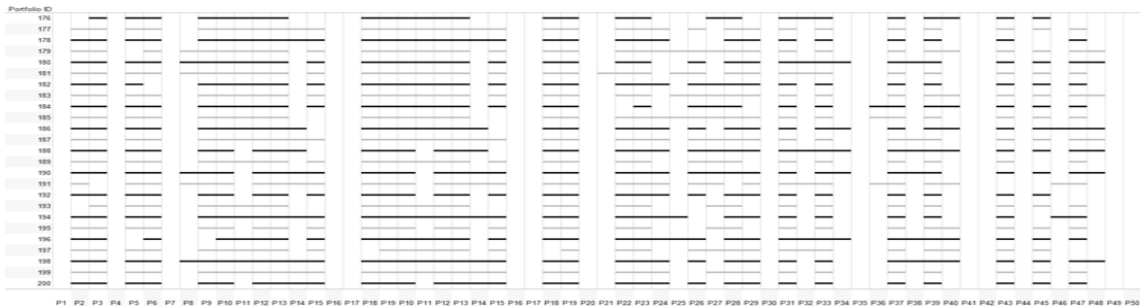


Figure 8.15: Visualisation - Details - Selected Projects

## 9 Discussion

In this section of the thesis the results of the presented work are compared with the research issues defined in chapter 3. A framework for project portfolio decision support using evolutionary algorithms is presented in this work. The framework presented is separated into two phases. The first phase focuses on the preparation of the business environment to conduct portfolio optimisation, and consequently creates optimised portfolios with the help of an evolutionary optimisation algorithm. In the second phase, a group decision support process is used for the selection of one portfolio out of the pareto-optimal front.

The presented approach to portfolio optimisation and selection is inspired by previously published works on the topic of mathematically based portfolio optimisation. This part of the related work is summarised in section 2.6. The paper, *Interactive R & D Portfolio Analysis with Project Interdependencies and Time Profiles of Multiple Objectives* [42], is used to compare the presented work with a paper, which is well accepted in the scientific community. The comparison is presented subsequent to the comparison of the presented work with the defined research issues.

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Is the CIDECS framework useful to model complex decision problems?

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Research issue one, presented in section 3.1.1, deals with the question of whether CIDECS is useful to model complex decision problems. This research issue is answered on the one hand by the structure of this thesis, since the structure of this thesis follows the structure of CIDECS, whereas on the other hand by the subjective experience of the author in modelling this decision problem. In the search for a suitable structure for this thesis, CIDECS was a valuable guideline. It was very helpful to have an overview of the steps a decision support system has to be able to conduct, and how these steps are related to each other. Whether the structure of this thesis is suitable to present a decision support framework has to be judged by the reader. From the author's view, the structure was very helpful in creating the presented thesis, and is suitable to present all conducted work.

Thus, CIDECS has proven that it is able to support decision problem engineers.

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Which steps does a portfolio manager have to carry out in order to prepare the business environment for the process of portfolio optimisation?

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Research issue two, presented in section 3.2.1, deals with the question asking which steps a portfolio manager has to conduct to prepare the business environment for the process of portfolio optimisation? This research issue is answered in the presentation of a PPM process which is focused on the preparation of the business environment for portfolio optimisation. In following the process presented, the needed work has been done to create all needed data for the step of portfolio optimisation. This includes, for example, strategy ranking, setting preferences and pre-screening. This process is influenced by already published PPM processes. Whereas nothing really new is presented, precious techniques are presented to foster understanding of the PPM environment, and the process is focused to be straightforward. This process assumes that project data is available and maintained in a database. Since the presented process of portfolio optimisation is highly dependent on complete data sets, thoroughly conducted project management is a precondition to using this process.

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How could the portfolio optimisation environment, with its various goals and restrictions, be modelled in a generic formal model?

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Research issue three, presented in section 3.2.1, deals with the question of how the portfolio optimisation environment could be modelled in a generic formal model. Therefore a generic formal model was created, and is presented in section 5.2.1. The model presented is generic in a way that the solution could be applied to any kind of projects, especially for projects and a portfolio optimisation, where the start timeframes of projects do play a role. Furthermore, mathematical equations are presented to model maximisation, minimisation, objective soft preferences and resource usage. This formal model is combined with an explanation of how repair algorithms could be utilised in a portfolio optimisation implementation, in order to implement logical project dependencies and resource restrictions.

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How could the general portfolio optimisation goals XVIII, IX be supported by the optimisation approach?

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Research issue four, presented in section 3.2.3, deals with the question of how the optimisation approach could support the selection of projects in respecting their possible timeframes. A solution to this research issue is presented in the solution representation of the formal model. The solution model is expanded from the commonly used 0-1 solution representation, to a *0-possible starting timeframes* solution representation vector, enabling the used evolutionary algorithm not only to optimise portfolios regarding the selected projects, but also to select the starting timeframe of the projects, from the list of possible starting timeframes of each project. Thus, the proposed approach is able to conduct optimisation in the sequencing of projects. Test runs have shown that this approach works really well.

Furthermore, this research issue deals with the question of how negative synergy effects between projects can be considered in the optimisation approach. This is achieved by introducing an objective to minimise negative synergies. In the test runs, a combined synergy effects objective is used, in which negative synergy is subtracted from the positive synergy. Analysis of the results of mPOEMS does show that mPOEMS is able to optimise portfolios with respect to this objective. This is proven in the analysis of the combined synergy result. The mean value of the negative synergy is significantly lower than the mean value of the positive synergy, whereas the maximum synergy values are almost equal for both parts. 206350 for the negative synergy part, and 213100 for the positive synergy part. This lead one to conclude that the algorithm does prefer combinations of projects which lead to higher overall synergy, and thus demonstrate the effectiveness of the combined synergy objective. A detailed analysis of the results of the test runs with mPOEMS can be found in section 7.3.2.

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Is the Evolutionary Algorithm mPOEMS suitable to solve the project selection problem?

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Research issue five, presented in section 3.3.1, deals with the question of whether mPOEMS is suitable to solve the project selection problem. From the author's point of view,

mPOEMS is a suitable candidate to solve the project selection problem. Results of the test runs do show that mPOEMS is able to create, maintain and optimise a set of portfolios. It is shown that mPOEMS is able to handle numerous objectives, constraints and restrictions. Thus, mPOEMS can be regarded as an ideal candidate for the project selection problem, able to handle complex optimisation problems.

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Which steps have to be carried out to adapt the Evolutionary Algorithm mPOEMS to solve the project selection problem?

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Research issue six, presented in section 3.3.2, deals with the question of how mPOEMS has to be adapted to solve the project selection problem. A previously implemented, generic JAVA framework of mPOEMS is used [24], which can be easily adapted to arbitrary optimisation problems. Only the problem-specific part has to be designed and implemented. The previously created formal model of the project selection part served as a valuable guide for the implementation. The use of the generic mPOEMS in JAVA framework has shown that the JAVA framework can be easily adjusted to various problems, without much implementation effort.

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How does mPOEMS performs for the project selection problem, in comparison to state-of-the-art Evolutionary Algorithms?

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Research issue seven, presented in section 3.3.3, deals with the question of how the implemented project selection approach using mPOEMS performs in comparison with the two state-of-the-art search algorithms NSGA-2 and SPEA-2. The comparison in using the PISA framework ensured a very easy comparison of the search algorithms mentioned. The problem-dependent part of the mPOEMS could be easily attached into PISA, with slight modifications. The conducting of test runs was also straightforward, whereas only the correct ready-to-use implementations of NSGA-2 or SPEA-2 have to be started. In the comparison of this optimisation algorithms, numerous test runs have been conducted. Firstly to find the best configuration for the algorithms, and secondly to create enough solutions to be able to calculate significant results. The only drawback from the author's view is the missing possibility of automating test runs with different seeds. Thus, con-

ducting a lot of test runs, and manually changing configuration values was fairly time consuming and cumbersome. Besides this point, the author wants to recommend the PISA framework to any optimisation engineer who wants to compare different search optimisation algorithms. mPOEMS performed very well in comparison to NSGA-2 and SPEA-2. In two out of three metrics, mPOEMS did perform better than NSGA-2 and SPEA-2. Furthermore mPOEMS is able to better optimise the objectives together, preventing extreme values in some objectives, while other objectives are very bad, and thus mPOEMS is from a practical point of view the best algorithm under consideration.

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How could the process of selecting one portfolio out of the pareto-optimal front, be adapted to a group of decision makers?

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Research issue eight, presented in section 3.4.1, deals with the question of how a group decision support process can support decision makers in extracting one portfolio out of the pareto-optimal front, which is created in the optimisation step. The findings of this investigation are that a decision model, including decision rules and preference functions can help to quantify subjective preference. Quantification is necessary in order to visualise the subjective preference values. The approach discussed is divided into two steps. In the first step, the decision maker is asked to weight the available objectives. This weighting is multiplied by the normalised objective values of each solution, resulting in a preference value for each solution, which obeys the order- and transitivity axiom. Thus, in the first step, a ranking of the solutions is conducted, which is based on a weighting of the available objectives. In the second step, arbitrary decision rules can be used to modify the calculated preference values. Must-, Must not-, and should-decision rules give the user the potential to modify the preference values for the solutions, based on subjective preferences. If a relative ranking based on the weighting of the objectives is not desired, this step could be omitted and a mean value could be given to each solution. The relative ranking of the solutions would be created in the second step, based on the subjective preferences of the decision maker. Consequently, these preference values are encoded as colour and size in the visualisations used in the group decision process, instantly presenting to the user the preference values of all decision makers who take part in the decision process. With this approach an easy-to-use decision process is created, which enables the decision makers to facilitate the search for consent in individual preferences.

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What are suitable visualisation and data exploration techniques for the group decision process?

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Research issue nine, presented in section 3.4.2, deals with the question of how the group decision process could be supported with visualisation and data exploration techniques. In the related work section about *Visualisation of multi-dimensional data* in section 2.8, some sophisticated visualisation techniques have been presented. For the proposed group decision process, standard visualisation techniques like X-Y plots and bar-charts have been used. In order to visualise the multi-dimensional pareto-front, a concept of linking and brushing, combined with various standard visualisation techniques is used. The user is given an easy-to-use tool to exclude solutions which do not meet the preferences of individuals, or certain other aspects. The author thinks that sophisticated visualisation techniques would have great potential for the presentation of multi-dimensional portfolio data, and wants to recommend this open work for further research, especially a technique to visualise the different sequencing of the projects in the portfolios would be interesting.

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How could individual preferences be easily inserted into the group decision process?

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Research issue ten, presented in section 3.4.3, deals with the question of how individual preferences could be easily inserted into the group decision process. This research issue is already answered in the discussion about research issue eight. With the proposed approach with decision rules and preference functions, a group of decision makers is given an easy-to-use tool to insert individual preferences into the group decision process.

After the comparison and discussion of the research issues with the results of this thesis, the proposed approach is compared with related work in the field of mathematically based portfolio optimisation and decision support. The well accepted paper in the scientific community, *Interactive R & D Portfolio Analysis with Project Interdependencies and Time Profiles of Multiple Objectives* [42], is used for this purpose. In the mentioned paper, a two-phase decision support system for portfolio optimisation is presented, and the approach is tested with R & D project data. A direct comparison is difficult, since the approach presented in the paper, and the approach presented in this thesis, are focused

on different kinds of projects. Nevertheless, the used portfolio optimisation characteristic can be compared, as can the proposed portfolio decision support approach.

In the paper under consideration, resource consumption is viewed in corresponding timeframes. A 0-1 solution representation is used to state whether a project is selected for a portfolio or not. Interdependency constraints are used which are not restricted in the number of projects in the interdependency chain that could be handled. Logical and strategic constraints, like certain numbers of projects assigned to a specific category, are considered as restrictions. Resource and benefit constraints are also considered as maximum and minimum restrictions. Special emphasis should be placed on the necessary calculation time to find the pareto-optimal front of the presented complex problem. Only a few seconds are needed to calculate all feasible portfolios. As stated in the paper, this feature may not be critical, since the calculation is probably conducted days before the interactive decision is conducted [42]. The interactive decision support system seems to guide the user well through the process of exploring the solution space and selecting one portfolio, whereas the process mentioned is not applicable to a group of decision makers.

In the optimisation approach presented in this thesis, a solution representation is used which allows the utilised optimisation algorithm to optimise the portfolios not only in selecting projects, but also for optimising the sequence of projects. Consideration of the project starting timeframes and a detailed calculation of the resource consumption, with respect to the selected starting timeframe results in an in-depth optimisation of project selection and sequencing. For example, the resources consumed by a project are broken down into units of months and the resource consumption is summed up for the timeframes in which the project will be conducted. Furthermore the combination of a restriction regarding the resources, with an objective to optimise, lead to portfolios that have optimised resource utilisation in each of the timeframes observed. This is a very detailed approach to project selection and consideration of resource consumption, and shows the general feasibility of such a detailed approach. The relevance of this approach for a real business has to be tested. Nevertheless, the approach related to in this thesis is more detailed than the approach regarding resource consumption presented in paper [42]. Whether such a detailed resource consumption analysis is needed in real business should be considered in future research. The general feasibility has been proven.

The interdependencies consideration is restricted to have more than three projects in one chain. This restriction was introduced because of the complexity of the implementation of an interdependencies chain with more than three projects in one chain. Theoretically, the number of projects in one chain is not restricted. The complexity is based on the consideration of the starting timeframes of each project, and for each chain, possible



starting combinations have to be calculated using the presented algorithm. This is already complex for a chain of length three, and is becoming more and more complex for each project. To achieve ultimate flexibility, all possible starting timeframe combinations are calculated by the algorithm, and the optimisation selects one of the possible combinations. In paper [42] it is not clear to the author of this thesis whether it is considered in the optimisation approach that a project must finish before a dependent project can start. This is also considered in the presented approach. Nevertheless, the paper [42] is superior in this part, since the length of the interdependencies chain is not restricted.

The JAVA approach presented needs approximately three to five minutes to calculate an approximation of the pareto-optimal front. Thus, regarding the calculation time, the approach presented in [42] is better. This is probably not a decisive point, since calculation of the pareto-optimal front, and the decision of which portfolio is selected is probably conducted within a time range of a few days. Regarding the decision support to choose one portfolio out of the pareto-optimal front, a group decision process is presented. Since this was claimed by the authors of [42] as future work, the presented group decision process can be considered as a new method in this field of portfolio optimisation. The approach presented is only tested on an artificial test set of fifty projects. In the paper [42], the approach is tested with real project data. Further research should be done for the presented approach to test whether the implementation also works well for real-world data.

The comparison of these two approaches is meant only to show the different methods used in these two approaches to portfolio optimisation. Whether one approach is better than the other, cannot be judged in an objective way. Both approaches are unable to deal with incomplete data sets. The approach presented by Medaglia, Graves and Ringuest [33] presents a way to deal with uncertainty and incomplete data sets. The main goal of PPM should be the availability of complete data sets. Since this is often not possible in the PPM environment in a real business, further research should be done on how this topic could be inserted into the observed optimisation approach.

For the approach presented in this thesis, the author wants to say that the approach is very detailed, and claims to consider all objectives, restrictions, and constraints found in the theory regarding the portfolio level, and combines them with some new and creative ways to deal with the very complex problem of project selection. The list of goals on the program level, to be found in section 3.2, have not been implemented. For example, projects are not grouped into programs, and thus no data is calculated on the program level. In order to adapt the approach to program management, further research should be done to answer the question relating to which characteristics projects are grouped to-

gether, and which benefit one could have in grouping projects together in the optimisation process. Furthermore, it has to be investigated how manual adjustments could be made possible for the decision makers in the process of selecting a portfolio. This is probably only possible if the presented framework is implemented in one software program. The usefulness of the presented decision support system has to be investigated in a real business, and is subject to further research.

# 10 Conclusion

This thesis presents a framework for a decision support system in the field of portfolio optimisation. The framework is separated into two parts. The first part presents an approach to project selection and portfolio optimisation, utilising the evolutionary search and optimisation algorithm mPOEMS. Numerous objectives, restrictions, constraints and objective preferences can be handled by the presented portfolio optimisation implementation. Output of the first part is a set of efficient portfolios with respect to all objectives under consideration. This set is commonly referred to as the pareto-optimal front. In the second part, a group decision process is presented, which is able to guide a group of decision makers through the task of selecting one portfolio from the pareto-optimal front. This process is designed to be easy-to-use and facilitates the search for consent in individual preferences through the use of visualised preference values. A comparison of the used evolutionary algorithm mPOEMS with the two state-of-the-art search and optimisation algorithms NSGA-2 and SPEA-2, showed that mPOEMS performed better for the problem at hand with respect to two out of three multi-objective optimisation metrics.

Findings can be briefly summarised as follows:

- The framework presented is able to combine multi-objective optimisation with subjective preference visualisation.
- mPOEMS is able to deal with very complex optimisation problems. Proof-of-concept is presented in applying mPOEMS to the project selection portfolio optimisation problem.
- Performance comparison with the two state-of-the-art algorithms NSGA-2 and SPEA-2 showed that mPOEMS performs best in tuning all objectives together, which is one of the main objectives of multi-objective optimisation.
- The PISA platform, used for the performance comparison, is easy to use, and greatly facilitates the comparison of search and optimisation algorithms.
- A new method is proposed to enable the portfolio optimisation to not only conduct optimisation in the selection of projects, but also in the sequencing of projects, thus performing resource usage optimisation.

- A method to deal with objective criteria like number of categories assigned to a specific category in a portfolio is proposed. This method considers such criteria as another objective to optimise and combine it with restrictions which can be relaxed.
- The group decision process presented enables the user to easily add individual preference values into the decision process.

Various topics are subject to future work. The test set with which the approach was tested included fifty projects. It should be investigated how the performance of the optimisation algorithms under consideration change for test sets with a greater number of projects, and more interdependencies to take care off. Regarding the test set it would be important to test the approach on a test set with real-world data. The relevance of the proposed project sequencing optimisation and resource usage optimisation for real-world businesses would be also an interesting topic for further research. This could be investigated in conducting a survey in businesses which use portfolio optimisation. The presented approach is unable to deal with incomplete data sets and uncertainty is only considered in the risk metric. Therefore it should be investigated how this optimisation approach could deal with incomplete and uncertain data. The presented group decision process does not use sophisticated visualisation techniques. It should be investigated how such techniques, for example stardimates, could improve the presentation of the multi-dimensional portfolio data. Especially, the visualisation of the project sequencing, in combination with the visualisation of the optimised resource usage per timeframe would be an interesting field of research. Furthermore, a workshop should be conducted to get feedback of decision makers on the presented optimisation framework.

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# List of Figures

2.1	Links Among Process Groups; Source: [15]	8
2.2	Planning Process Group; Source: [15]	9
2.3	Planning Process Group; Source: [38]	24
2.4	Key program management relationships and goals; Source: [32]	26
2.5	The interconnecting responsibility of PPM; Source: [31]	29
2.6	Possible Portfolio Relationships; Source: [37]	30
2.7	Archers Framework for Portfolio Selection; Source: [1]	31
2.8	PMI PPM Process; Source: [37]	34
2.9	One Level Hierarchy	40
2.10	Two Level Hierarchy	42
2.11	Global ranking	42
2.12	Pareto Optimal Front	51
2.13	Outline of the mPOEMS algorithm	52
2.14	Outline of the MOEA used in mPOEMS	53
2.15	Two Knapsacks, 750 Items	53
2.16	Parallel Coordinates showing a car data set	55
2.17	Treemap with five branches	55
2.18	Stardinate with five dimensions	56
3.1	Collaborative Interactive Decision Support	59
5.1	Proposed PPM Process	70
7.1	Illustration of the Non-Covered-Space Metric	92
7.2	Testset - Project Interdependencies	94
7.3	PISA - Working Principle	99
8.1	Visualisation - Entry Dashboard	113
8.2	Visualisation - Brush and Exclude - View One	114
8.3	Visualisation - Brush and Exclude - View Two	114
8.4	Visualisation - Brush and Exclude - View Three	115

8.5	Visualisation - Brush and Exclude - View Four . . . . .	115
8.6	Visualisation - Brush and Exclude - View Five . . . . .	116
8.7	Visualisation - Brush and Exclude - View Six . . . . .	116
8.8	Visualisation - Dynamic Filters - View One . . . . .	117
8.9	Visualisation - Dynamic Filters - View Two . . . . .	118
8.10	Visualisation - Dynamic Filters - View Three . . . . .	118
8.11	Visualisation - Results - Overview . . . . .	119
8.12	Visualisation - Results - Selected . . . . .	119
8.13	Visualisation - Details - Synergy . . . . .	120
8.14	Visualisation - Details - Category . . . . .	120
8.15	Visualisation - Details - Selected Projects . . . . .	121

# List of Tables

2.1	COCOMO II Scale Factors . . . . .	19
2.2	COCOMO II Early Design Effort Multipliers . . . . .	19
2.3	COCOMO II Phase Distribution Percentages . . . . .	20
2.4	Weighted Risk Factors in Percent . . . . .	21
2.5	AHP Judgement Scale; Source: [40] . . . . .	40
2.6	AHP Strategy Prioritisation . . . . .	41
2.7	Strategy Scoring Model . . . . .	43
2.8	Score Level; Source: [31] . . . . .	43
2.9	Non-Dominance . . . . .	50
3.1	Goal Summary . . . . .	61
7.1	Cost and Schedule Creation Steps . . . . .	86
7.2	SF Ratings . . . . .	86
7.3	Cost Driver Ratings . . . . .	87
7.4	Schedule and Effort per Phase . . . . .	87
7.5	PMM for Months 1 to 10 . . . . .	87
7.6	PMM for Months 11 till 19 . . . . .	88
7.7	CM for Months 1 till 7 . . . . .	88
7.8	CM for Months 8 to 13 . . . . .	89
7.9	CM for Months 14 to 19 . . . . .	89
7.10	Solution Quality Criteria . . . . .	91
7.11	Test Set Quality Criteria . . . . .	92
7.12	HVM Results for mPOEMS . . . . .	97
7.13	Analysis - Various Metrics . . . . .	97
7.14	HVM Results for SPEA-2, NSGA-2 and mPOEMS . . . . .	102
7.15	Size of the Non-Dominated Front . . . . .	102
7.16	Coverage Results for SPEA-2, NSGA-2 and mPOEMS . . . . .	103
7.17	Interval Results for mPOEMS . . . . .	103
7.18	Interval Results for SPEA-2 . . . . .	104

7.19	Interval Results for NSGA-2 . . . . .	104
7.20	Max - Min Ratio for SPEA-2, NSGA-2 and mPOEMS . . . . .	105
8.1	Simplified Set of Six Portfolios with Five Objectives . . . . .	107
8.2	Normalised Objectives of a Simplified Set of Six Portfolios . . . . .	108
8.3	Allocated Points for Two Decision Makers . . . . .	108
8.4	Weighted Solutions For Two Decision Makers . . . . .	108
8.5	Allocated Points for Five Decision Makers . . . . .	112

# Abbreviations

<b>AHP</b>	Analytic Hierarchy Process
<b>CIDECS</b>	Collaborative Interactive Decision Support
<b>CM</b>	Cost per Month
<b>CD</b>	Cost Driver
<b>COCOMO</b>	Constructive Cost Model
<b>EA</b>	Evolutionary Algorithm
<b>EM</b>	Effort Multiplier
<b>FCIL</b>	Facilities
<b>FLEX</b>	Development Flexibility
<b>FP</b>	Function Points
<b>HVM</b>	Hyper-Volume-Metric
<b>IT</b>	Information Technology
<b>KSLOC</b>	Thousands(K) of Source Lines of Code
<b>MBASE</b>	Model-Based Architecting and Software Engineering
<b>MOEA</b>	Multiobjective Evolutionary Algorithm
<b>mPOEMS</b>	Multiobjective Prototype Optimization with Evolved Improvement Steps
<b>nop</b>	no operation
<b>NPV</b>	Net Present Value
<b>NP</b>	Nondeterministic Polynomial-Time
<b>PDIF</b>	Platform Difficulty
<b>PERS</b>	Personnel Capability
<b>PM</b>	Person Months
<b>PMAT</b>	Process Maturity
<b>PMI</b>	Project Management Institute
<b>PMM</b>	Person Months effort per Month
<b>PPM</b>	Project Portfolio Management
<b>PREC</b>	Precedentedness
<b>PREX</b>	Personnel Experience
<b>RCPX</b>	Product Reliability and Complexity
<b>RESL</b>	Architecture / Risk Resolution

**ROI** Return On Investment  
**RUDM** Resource Usage Distribution Metric  
**RUP** Rational Unified Process  
**RUSE** Developed for Reusability  
**SAV** Strategic Alignment Value  
**SCED** Required Development Schedule  
**SF** Scale Factors  
**SLOC** Source Lines of Code  
**TEAM** Team Cohesion  
**TDEV** Time to Develop  
**WBS** Work Breakdown Structure