A DECISION SUPPORT MODEL FOR ADOPTING SOFTWARE PRODUCT LINE ENGINEERING

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ABSTRACT

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The software product line engineering (SPLE) community has provided several different approaches for assessing the feasibility of SPLE adoption and selecting transition strategies. These approaches usually include many rules and guidelines which are very often implicit or scattered over different publications. Hence, for the practitioners it is not always easy to select and use these rules to support the decision-making process.

To support the decision-making process in SPLE adoption, a decision support model is introduced for pursuing SPLE transition. A prototype tool, *Transit-PL* is developed after a domain analysis study on the feasibility analysis approaches and SPLE transition strategies in the literature. The decision support model has been developed and enhanced through exploratory case studies, and then further validated in both literature-based retrospective case studies and real life prospective case studies. The multiple case study validation showed that proposed decision support model has a clear impact on the decision-making process in SPLE adoption.

Keywords: software product line engineering, software product line transition strategies, software product line engineering feasibility analysis, decision support model, decision support system

ÖZ

YAZILIM ÜRÜN HATTI MÜHENDİSLİĞİNE GEÇİŞ İÇİN BİR KARAR DESTEK MODELİ

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Yazılım ürün hatları mühendisliği (YÜHM) geçiş olabilirliği ve strateji seçimi konusunda, literatürde bir çok çalışma yapılmıştır. Bu çalışmalar faydalı tavsiyeler içermesine rağmen, bu bilgiler birçok yayına dağınık ve örtülü şekilde olduğu için, uygulayıcılar için karar verme sürecinde bu kuralları seçmek ve kullanmak her zaman kolay değildir.

Bu çalışmada yazılım ürün hatları mühendisliğine geçiş için bilgisayar destekli bir karar destek modeli önerilmiştir. Yazılım ürün hattı mühendisliğine geçiş olabilirliği ve stratejileri konusunda ayrıntılı bir alan analizi çalışmasından sonra prototip bir araç olan *Transit-PL* geliştirilmiştir. Önerilen karar destek modeli, örnek olay çalışmalarıyla olgunlaştırıldıktan sonra literatürde yer alan geçmiş olay öyküleri üzerinden ve yazılım şirketlerinde denenerek doğrulanmaktadır. Karar destek modelinin karara etkisi çoklu olay çalışmaları ile ispatlanmıştır.

Anahtar Kelimeler: yazılım ürün hattı mühendisliği, yazılım ürün hattı mühendisliğine geçiş stratejileri, yazılım ürün hatları mühendisliği fizibilite analizi, karar destek modeli, karar destek sistemi

To My Family

ACKNOWLEDGMENTS

I always wanted to return to Graduate School for my PhD, but just could not find the right time for this challenging activity with several years of working abroad and then back home. Once I realized that there is no ‘right time’ to start, this whole PhD experience turned out to be a wonderful mental journey for me, of course with the help of several people.

First of all, I would like to express my deepest gratitude to my supervisor Prof. Dr. Semih Bilgen for his guidance and suggestions throughout the whole process. He provided me with great vision and advice to complete my dissertation. He is always a great role model for me with his patience, understanding and vision.

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I would also like to thank the jury members; Prof. Dr. Onur Demirörs and Assist. Prof. Dr. Özgür Tanrıöver for their valuable comments and suggestions throughout the last few years, Assoc. Prof. Dr. Aysu Betin Can and Assoc. Prof. Dr Altan Koçyiğit for reading and commenting on the final version of the thesis. Special thanks to Mert Emin Kalender who implemented *Transit-PL* and made several improvements to the tool throughout the thesis.

This thesis could not have been completed without the support of my company HAVELSAN and my co-workers. I also wish to mention one more person who was a very influential in the early years of my career, Professor Evan Eichler. He was one of the first persons who made me believe in myself on a path to PhD several years ago while I was working as a software engineer on a totally different subject in his research lab in Seattle.

Last but not least, I am very lucky to have a wonderful family that unconditionally supports me pursuing my goals: my parents, my dearest brother and my parents-in-law. Most of all, I am grateful to my wife Selen, for her infinite moral support and love, particularly over the countless weekends and week nights I left her alone with our new family member; Toprak. This work is dedicated to my son Toprak, who not only survived to grow up without me around him at times, but for a wish that he will, one day, enjoy studying and research as much as I do.

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LIST OF ABBREVIATIONS

ACM	:	Association for Computing Machinery
ALM	:	Application Lifecycle Management
BAPO	:	Business, Architecture, Process, Organization
C2	:	Command and Control
C4ISR	:	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CEO	:	Chief Executive Officer
CMMI	:	Capability Maturity Model Integration
DSM	:	Decision Support Model
DSS	:	Decision Support System
EGM	:	Engineering Group Manager
IEEE	:	Institute of Electrical and Electronics Engineers
PLQL	:	Product Line Quick Look
PLTP	:	Product Line Technical Probe
ROI	:	Return on Investment
SEI	:	Software Engineering Institute
SGM	:	Software Group Manager
SM	:	Software Management
SLR	:	Systematic Literature Review
SPL	:	Software Product Lines
SPLC	:	Software Product Line Conference
SPLE	:	Software Product Line Engineering

CHAPTER 1

INTRODUCTION

1.1 Background and Motivation

According to Boehm [1], there are mainly three ways to improve productivity in software development. You can work faster, by using tools that would automate some of the labor-intensive task. You can work smarter, by mainly process improvements. Or you can avoid unnecessary work by software reuse, which will offer the biggest potential payoffs.

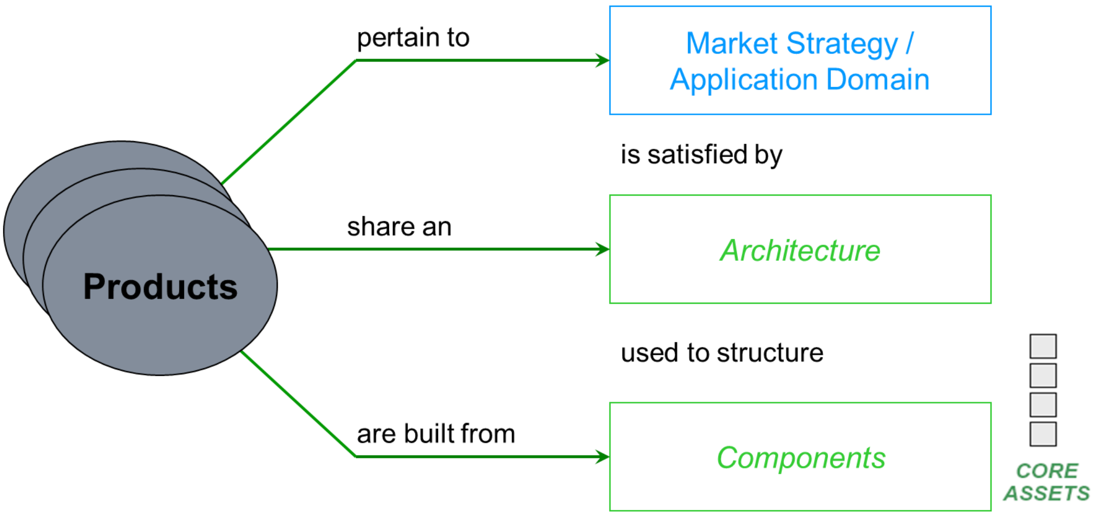

Figure 1. Software Product Lines (Adapted from [2]**)**[1]

Software reuse has been an important goal in the history of software engineering [3]. Early reuse approaches such as abstract data types, module-based programming, component-based software development, reusable libraries and design patterns, could be basically categorized as small-scale reuse [3]. Over the decades, the notion of *application frameworks* has been introduced as a mechanism for supporting large scale reuse instead [4]. An application framework is a reusable, "semi-complete'' application that can be specialized to produce

[1] All material, including figures, tables and text, in this document is strictly original, unless the source from which any adaptation has been realized is explicitly referenced.

custom applications [4][5]. The general idea on large-scale software reuse and the research and practice on application frameworks seem to have culminated in the notion of software product lines (Figure 1).

Currently an increasing number of companies aim to adopt an SPLE approach with the goals of enhancing the quality of products, reducing time-to-market and optimizing production costs. The benefits for adopting SPLE have been extensively documented (e.g. [5][6][8]) and discussed in experience reports (e.g. [9][10][11]). On the other hand, it is commonly accepted that the transition to software product line engineering is not easy. In general it requires large upfront investment and as such, constitutes a serious risk if the desired return-on investment is not achieved. To illustrate this situation, consider for example the following typical scenario, derived from an industrial context:

The engineering group manager of an organization that builds simulation systems is at a junction. The organization has delivered a number of successful simulation system projects over the last few years. Even though the simulation systems have a lot of common features, traditionally these systems were implemented using a single systems development approach. The company is aware that the reuse potential has not been used. Recently there has been increasing pressure to decrease the costs and time-to-market of these systems. The manager has heard about Software Product Line Engineering, which has been adopted by some of his company's competitors and is aware of the potential benefits of SPLE. However because of the risks associated with SPLE, it has not been easy to reach a decision. After all, considerable investment needs to be made and a wrong decision in this case could be dramatic. On the other hand, if a proper decision is made for the adoption of SPLE and the corresponding strategy, the risks could be mitigated and the expected return on investment could be achieved.

In the context of this scenario two different decisions need to be made. First of all, it should be decided whether adopting an SPLE approach is indeed feasible for the organization. Secondly, if the adoption of SPLE is feasible, a decision should be made regarding the selection of an appropriate SPLE transition strategy. The software product line engineering (SPLE) community has provided several different approaches for assessing the feasibility of SPLE adoption and selecting transition strategies. The feasibility of SPLE adoption is defined as the go/no-go decision point for adopting SPLE, whereas the transition strategy is a set of steps needed to transition from the currently adopted approach to SPLE. These approaches usually include many rules and guidelines that can assist the decision-maker to analyze the feasibility of SPLE adoption, and select a proper transition strategy. Unfortunately, there are many different rules which are very often implicit or scattered over different publications. Even in cases where the rules are known, manually processing these rules is not trivial, and requires considerable knowledge and experience. Hence, for the practitioners it is not always easy to select and apply these rules to support the decision-making process. To support the decision-making process it would be worthwhile to accumulate the rules and provide automated support to assist the decision-makers.

The literature on SPLE reveals that the Business-Architecture-Process-Organization (BAPO) framework for characterization of organizations for suitability and effectiveness in SPL implementation is very widely accepted, almost constituting a de-facto standard for assessment. In line with that understanding, in the present study, we adopt the same framework, and develop an original set of rules for decision making towards evaluation of feasibility and selection of transition strategy.

1.2 Objective of the Study and Research Questions

We introduce a decision support model (DSM) to support decision-makers for SPLE feasibility analysis and selection of transition strategies. In alignment with this goal, we implement a corresponding decision support system (DSS) to evaluate the impact of the proposed decision support system on decision making in SPLE adoption.

To support the objective of the study, two main research questions were formulated:

- RQ1: How can the SPLE feasibility of an organization with particular characteristics be assessed?
  - RQ1.1: What are the existing SPLE feasibility analysis approaches?
  - RQ1.2: What are the aspects that impact the decision on SPLE feasibility?
  - RQ1.3: What are the questions and rules that are used in the decision-making process for SPLE feasibility?
- RQ2: How can an appropriate transition strategy for an organization with particular characteristics be selected*?*
  - RQ2.1: What are the existing SPLE transition strategies?
  - RQ2.2: What are the aspects that impact the decision on SPLE transition strategies?
  - RQ2.3: What are the questions and rules for selecting proper transition strategies?

1.3 Research Methodology

Since the final aim of this PhD thesis is to design a decision support model and corresponding decision support system for SPLE feasibility and transition strategy selection, we have used Design Science Research approach as presented in [12][13]. Details of our research methodology are depicted in Figure 2.In the *Awareness of Problem* phase, the need for decision support in SPLE adoption emanated from the context of an industrial company. The output of this phase was a proposal for a set of initial research questions. In the *Suggestion* phase, to collect more detailed knowledge related to the problem, an extensive systematic literature review was carried out to derive the initial answers to the sub research questions. The output was a tentative design based on the initial answers to the research questions. The *development* phase aimed to develop artifacts that support and enhance the tentative design. The artifacts consisted of the decision support model and the corresponding decision support tool. In the *Evaluation* phase, the introduced decision support model was evaluated via multiple case studies in which the prototype decision support tool was applied to actual problems. These were based either retrospectively on published reports, or prospectively on interviews with responsible staff involved in SPL planning and transition. This phase was intentionally designed to be iterative, and led to multiple improvements to the Decision Support model and the decision support tool, based on feedback from the case studies. Finally in the *Conclusion* phase, the results of the research were compiled for presentation in this dissertation, and a number of manuscripts [14][15][16][17][18][19] were prepared for publication.

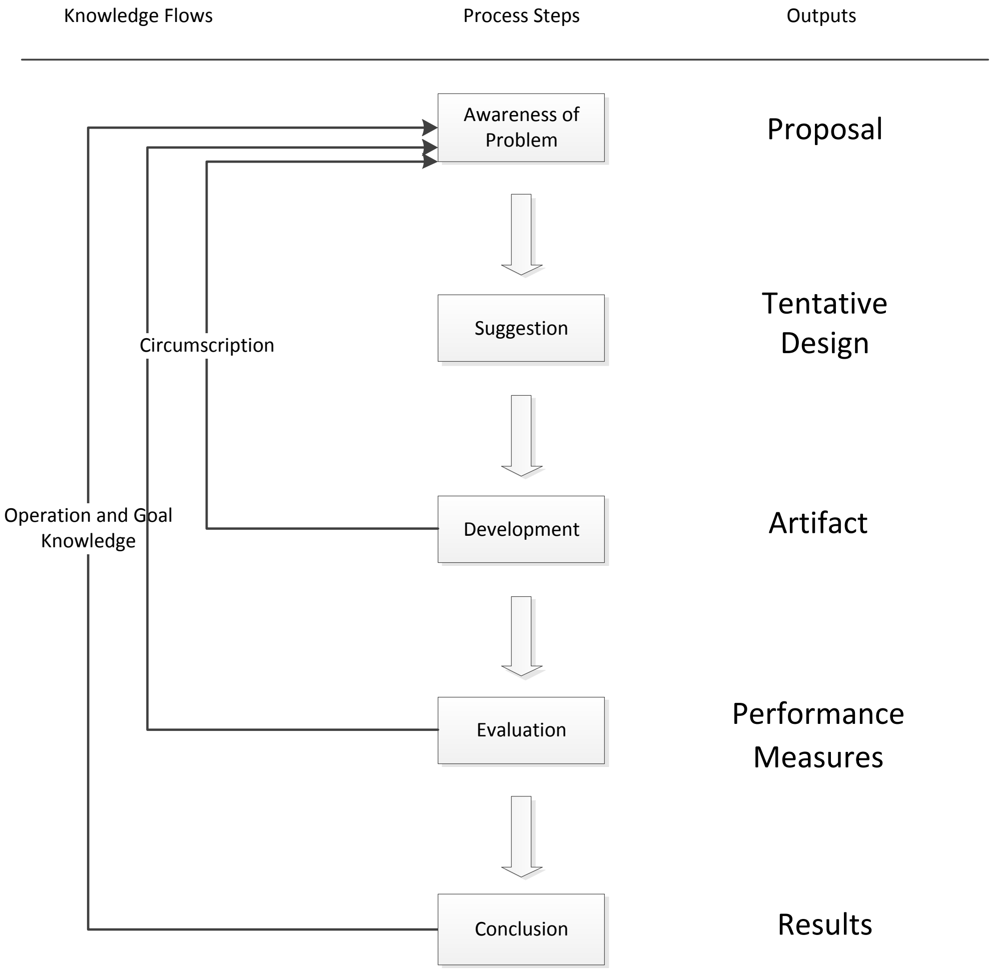

Figure 2. Research methodology of the PhD thesis (Adapted from [12]**)**

1.4 Outline

The remainder of the thesis is organized as follows. In Chapter 2 we provide the background for SPLE adoption in general and the related work. Chapter 3 presents the results of a systematic literature review on SPLE feasibility analysis and transition strategy selection. Chapter 4 presents the DSM and the DSS tool, *Transit-PL*, and Chapter 5 describes the multiple case study design. Chapter 6 presents the multiple case study results and finally Chapter 7 concludes the thesis.

Chapter 2

BACKGROUND AND RELATED WORK

In this chapter, background regarding SPLE adoption is presented. In Section 2.1, a general overview of SPLE is presented. In Section 2.2 we define the SPLE adoption problem.

2.1 Software Product Line Engineering Overview

In general there appears to be a consensus that the SPLE process consists of lifecycle processes of *domain engineering* and *application engineering.* This common SPLE process is shown in Figure 3. The domain engineering process is responsible for establishing the reusable platform and thus for defining the commonality and the variability of the product line [11]. The platform consists of all types of software artifacts (requirements, design, realization, tests, etc.). The domain engineering process is composed of five key sub-processes: *product management, domain requirements engineering, domain design, domain realization,* and *domain testing.* In the application engineering process, the applications of the product line are built by reusing the artifacts and exploiting the product line variability as defined in the domain engineering process. The application engineering process is composed of the sub-processes *application requirements engineering, application design, application realization,* and *application testing.*

The benefits for adopting a product line approach has been analyzed and discussed before by several authors [20][21][11][8]. The key motivation for adopting a product line engineering process is to develop products more efficiently, get them to market faster in order to stay competitive, and to produce with higher quality [22][8]. In support of these goals, different software product line engineering processes have been proposed such as, the SEI's Framework for Software Product Line Practice [21][23], the Fraunhofer's PULSE-approach [24], the Philips' CoPAM method [25], the FAST approach [26], and the Gomaa's PLUS approach [27]. Although different processes have been proposed, they share the same concepts of domain engineering, in which a reusable platform and product line architecture is developed, and application engineering, in which the results of the domain engineering process are used to develop the product members.

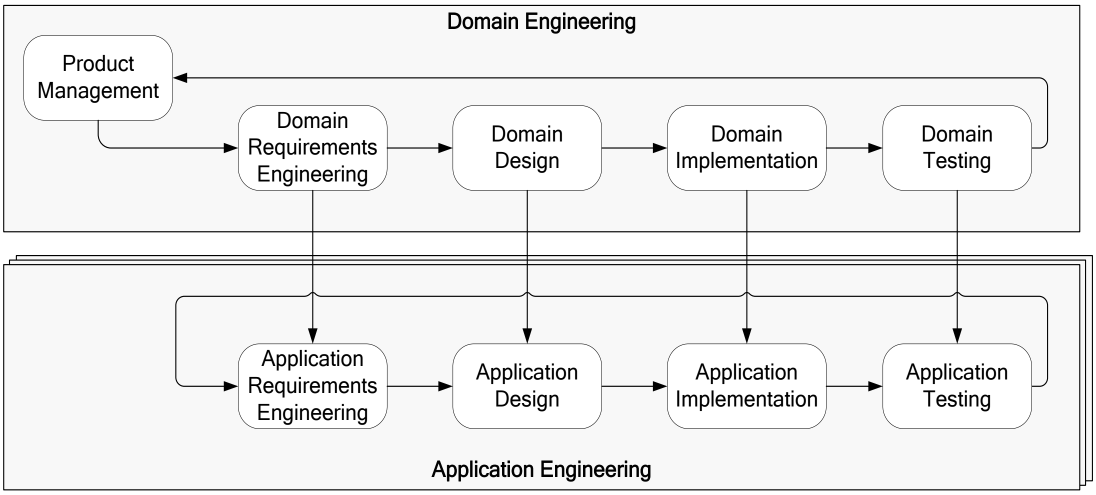

Figure 3. General SPLE Process

For transitioning to SPLE, it is important to define the proper cost models for providing the cost-benefit analysis of adopting an SPLE approach. The following represents the general formula for calculating the cost of adopting SPLE [6]:

$$C = C_{Org} + C_{Cab} + \sum_{i=1}^{n} (C_{Unique}(p_i) + C_{Reuse}(p_i)) \text{ (EQ1)}$$

Here, C represents the overall cost and consists of the cost of adapting the software reuse approach for the organization (C_{Org}), the cost to define the asset base (C_{Cab}), the sum of the cost for developing unique portion of the products (C_{Unique}) and the sum of the cost of reusing core assets (C_{Reuse}) for a software product line of n products denoted by p_i.

For calculating the development cost in single system development, only the cost for developing unique products is needed, (C_{org}), (C_{cab}), and (Cr_{euse}) can be omitted. As such, the cost model for this situation is shown in EQ2.

$$C = \sum_{i=1}^{n} (C_{Unique}(p_i)) \text{ (EQ2)}$$

Based on the general cost models, several other cost models for different scenarios have been defined [28][6]. An important point in the process of adopting an SPLE approach is the break-even point after which the organization will start to get the ROI for the upfront investment. Considering either the cumulative cost for developing products, or the time needed to deliver the products to the market, the ROI will be expressed differently. This is shown in Figure 4.

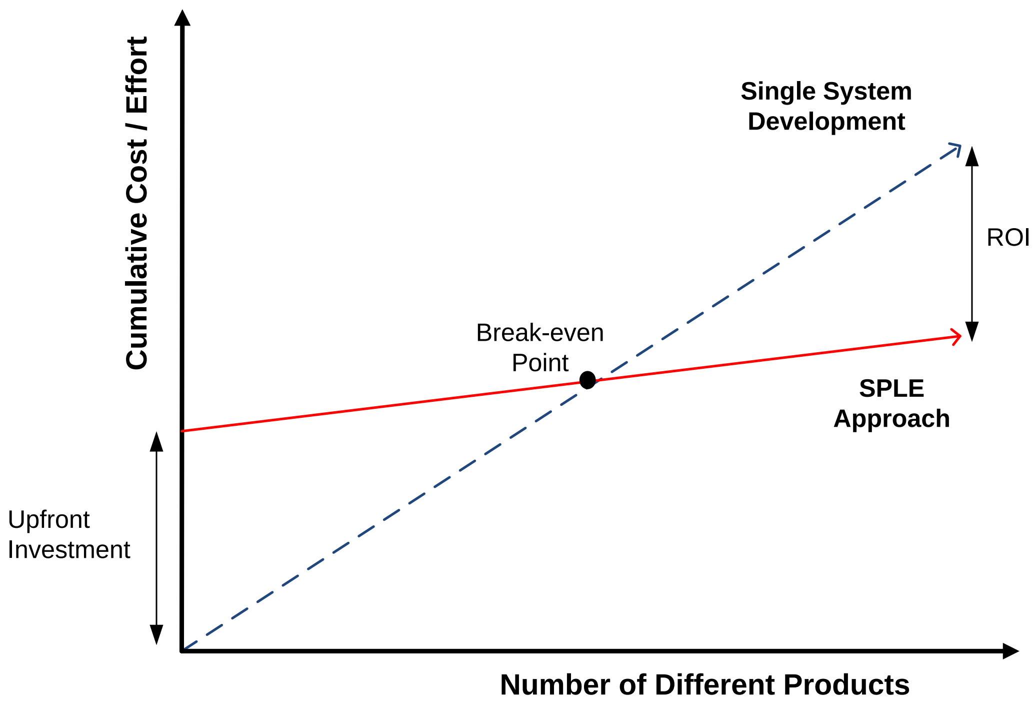

Figure 4. Typical ROI figure for Software Product lines

Typically, finding the break-even point is critical for an organization, since this will usually guide the decision for adopting SPLE or not. Although the exact location of the break-even point depends on various characteristics such as the organization and market characteristics, the range and kind of products, and the selected transition strategies, the break-even point is generally reported between 2 and 3 products by several authors [21][20][11][10]. The ROI of SPLE can be calculated by dividing the Cost Savings with Cost of investment. Cost savings can be calculated by subtracting the cost of SPLE approach (EQ1) from the cost of single development (EQ2).The cost of investment is (C_{org} + C_{cab}). As such, the formula for ROI can be expressed as follows:

$$\frac{\sum_{i=1}^{n} C_{Unique}(p_i) - (C_{Org} + C_{Cab} + \sum_{i=1}^{n} (C_{Unique}(p_i) + C_{Reuse}(p_i)))}{C_{Org} + C_{Cab}} \quad \text{(EQ3)}$$

Many software development organizations throughout the world have been striving to avoid duplication of effort in repeated development of similar products through reuse of software development artifacts. In theory, if systematic reuse approach such as SPLE has been used, after some number of products break-even point will be reached. However in practice, transitioning to software product line engineering is, in general, not a trivial move, and entails several risks. A break-even point may not be reached at all if SPLE approach is not appropriate in the first place; so it is crucial to assess the feasibility of SPLE approach at the outset, before the initial investment.

2.2 Software Product Line Engineering Adoption Problem

The methodology and roadmap for switching to product line engineering from a traditional way of software development is defined as adoption or transition, and an action plan for this process is called transition strategy [11]. To describe the concepts related to SPLE adoption process, Figure 5 shows the conceptual model that we have developed earlier [15].

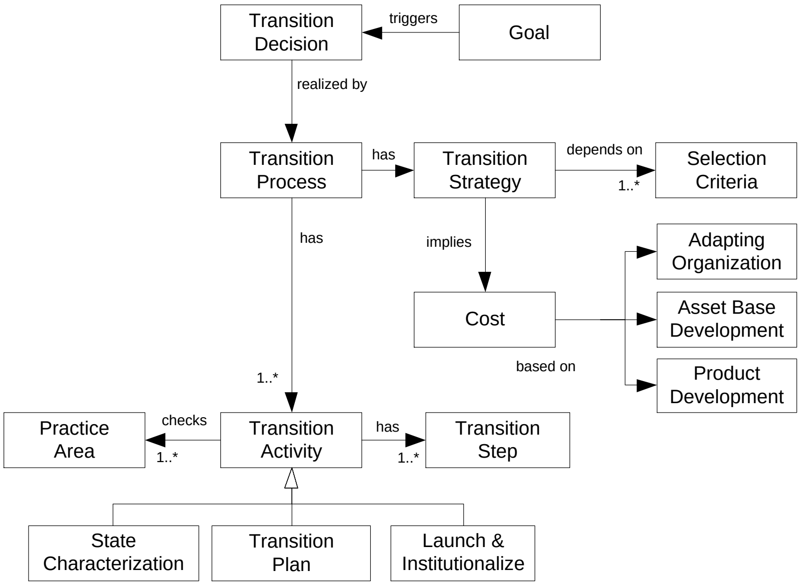

Figure 5. Conceptual Model for SPLE Transition Process (Adapted from [15]**)**

In general, SPLE adoption is triggered by a well-defined goal that can be either based on internal or external motivations. External motivation refers to purposes for external entities, such as the push of customers to include additional features in a short time. Internal motivation for transitioning to SPLE refers to improvements within the organizations, such as a need to improve project management to meet a certain schedule. These transition goals may trigger the business unit to define the decision to transition to a product line engineering approach or not. Typically, the transition decision is realized through a transition process which aims to transition the currently adopted single system development engineering to an SPLE approach. To carry out product line engineering, both knowledge and experience in the practice areas are needed. Practice areas define areas of knowledge including software engineering, organizational management and technical management areas [23]. The transition process is realized by adopting a transition strategy, which defines the strategic plan to transition the organization to a product line engineering approach. Each transition strategy will be determined by various criteria and imply a different cost including, cost for adapting the organization, asset base development and product development [11].

The transition process consists of a set of transition activities, which checks the maturity of adopted practice areas in the organization. Several transition activities can be identified including state characterization, transition planning, and launch and institutionalization. State characterization will define the current state of the organization that wishes to transition to a product line engineering approach. Typically, it will map out the state of the organization, the adopted process and the current artifacts. Transition planning provides the concrete plan for transitioning. Launch and institutionalization considers the implementation of the plan and the realization and operationalization of the product line engineering approach.

As stated before, the SPLE adoption is preceded by a decision-making process on both the feasibility of SPLE adoption and the transition strategy. In Figure 6, we present the decision-making process for SPLE feasibility and strategy selection process. Here, two different decisions need to be made. First of all, SPLE feasibility needs to be assessed to decide between continuing with the current approach and adopting SPLE. Secondly, if the adoption of SPLE is feasible, a decision should be made regarding the selection of an appropriate SPLE Transition strategy.

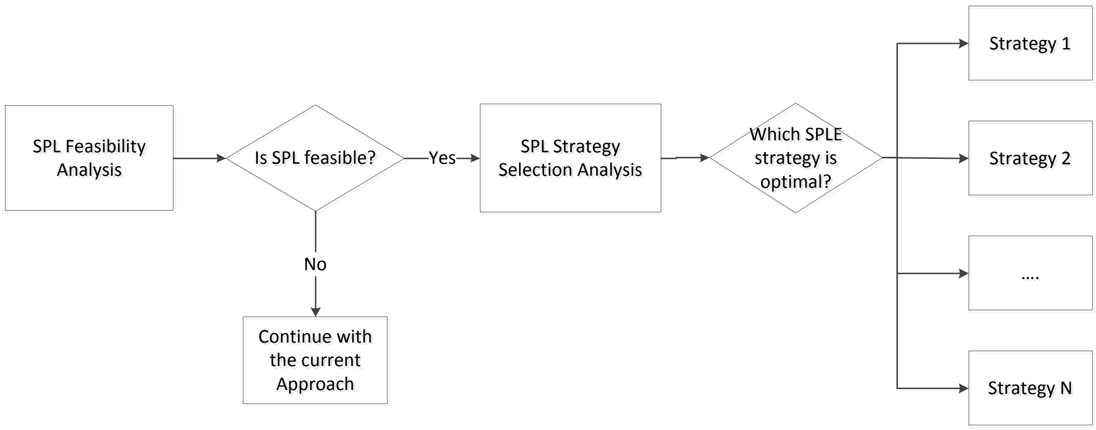

Figure 6. SPLE Feasibility and Strategy Selection Process

Chapter 3

SYSTEMATIC LITERATURE REVIEW

3.1 Primary Study Selection and Analysis

To derive the required knowledge for decision support for SPLE adoption, first, the existing SPLE adoption approaches in the literature will be reviewed. For this purpose, a systematic literature review was conducted using the guidelines described by Kitchenham [29].The SLR has been carried out with four researchers. In particular we are interested in the answers to the following research questions:

- What are the existing SPLE feasibility analysis approaches? (RQ1.1)
- What are the existing SPLE transition strategies? (RQ2.1)
- What are the aspects that impact the decision on SPLE adoption and transition strategies? (RQ1.2, RQ2.2)
- What are the questions and rules that are used in the decision-making process for SPLE feasibility? (RQ1.3)
- What are the questions and rules for selecting proper transition strategies? (RQ2.3)

RQ 1.3 and RQ 2.3 will be further refined in Chapter 4 while designing the Decision Support Model. It will be further iteratively modified throughout the case studies that are described in Chapter’s 5 and 6.

Our search scope included all the papers published before October 2013. The main motivation for 1996 was that SPL conferences started just after this date. We searched for full papers in selected venues that publish high quality papers. We used the following search databases: IEEE Xplore, ACM Digital Library, Wiley Inter Science Journal Finder, ScienceDirect, ISI Web of Knowledge, and other channels including Google Scholar Search and manual search channels. These venues are listed in Table 1. Our targeted search items were journal papers, conference papers, technical reports and workshop papers.

Table 1. Publication sources searched for the SLR

Source	Number of Included Studies After Applying Search Query	Number of Included Studies After Exclusion Criterion
IEEE Xplore	35	5
ACM Digital Library	15	2
Wiley Interscience	20	0
Science Direct	46	1
ISI Web of Knowledge	35	4
Google Scholar and Other Channels	995	19
Total	**1146**	**31**

To search the selected databases, we used both manual and automatic search strategies. Automatic search is realized through entering search strings to the search engines of the electronic data source. Manual search is realized through manually browsing the conferences, journals, books or other important sources and checking the references of selected papers. The manual searches appeared to be quite useful since we retrieved some good-quality articles that an automatic search could not reveal.

The search string was structured as follows:

("Software product line" OR "Software product family") AND (“migration” OR “adoption” OR “transition” OR “launching” OR "institutionalizing" OR "introduction" OR "introducing" OR "adopting" OR "adapting" OR "migrating" OR "transitioning" OR "Institutionalization" OR "transforming" OR "initiating") AND (“strategy” OR "feasibility" OR "potential" OR "barriers" OR "success factors")

In accordance with the SLR guidelines [29] we further applied the following exclusion criteria on the large number of papers in the first stage:

- Abstract or title does not explicitly discuss SPLE adoption.
- The paper does not explicitly discuss an approach for analyzing SPLE adoption
- Repeated in an already mined source.
- Most of the content is repeated in a similar paper (Extended version is chosen over the shorter one).

The exclusion criteria were checked manually by the four researchers. After applying the exclusion criteria, 31 papers of the 1146 papers remained. For data extraction and synthesis, we thoroughly studied the primary studies in detail to answer the four research questions. The identified primary studies (Appendix A) and the result of the data extraction and synthesis process are presented in the following sub-sections.

3.2 Data Extraction and Synthesis

3.2.2 What are the existing SPLE feasibility analysis approaches?

An SPLE feasibility approach defines the rules for deciding on the suitability of an SPLE approach for a given software project of a company. Based on the identified primary studies we could identify several software product line feasibility analysis approaches, which we describe below.

Product Line Potential Analysis [30] aims to quickly assess whether SPLE is suitable for a given set of products and market. The Product Line Potential Analysis is executed in a half-day workshop with a structured interview based on a questionnaire that examines products, software, markets, and customers. The answers provided to the questions are compared to a set of criteria for the applicability of the product line approach. The analysis results in either "yes" or "no" denote the suitability of SPLE, or the need for further investigation.

The *Product Line Technical Probe*, as defined by the Software Engineering Institute [21], includes the processes *Product Line Quick look* (PLQL) and *Product Line Technical probe* (PLTP) for examining the organization's readiness to transition to SPLE. PLQL is the initial gathering of the information about organization, while PLTP is a more thorough analysis of the organization for SPL readiness. Both PLQL and PLTP use the Framework Software Product Line Practice and Product Line Adoption Map as reference models [21]. PLQL consist of a one-day session where experts interview organization product line sponsors, primary technical leads and architects. PLTP consists of structured interviews of small groups that are selected from product line stakeholders. The results of the interviews are analyzed based on the 29 practice areas as specified in the framework.

Linden et al. [31] describe the Family Evaluation Framework which is based on four dimensions: *Business, Architecture, Process and Organization (BAPO)*. These four dimensions have been commonly taken (see e.g.[32][33][34]) as the basis for characterizing organizations according to their level of readiness for or their effectiveness in implementing SPLE. Each dimension includes an evaluation scale for assessing the organization. The overall evaluation will result in a profile of an organization in which the values of the four dimensions are given and explained. Each dimension has its own evaluation scale. The Business Evaluation has five levels; Reactive, Awareness, Extrapolate, Proactive and Strategic. The Architecture Dimension has the levels of; Independent Product Development, Standardized Infrastructure, Software Platform, Software Product Family, and Configurable Product Base. The Process Dimension is divided into; Initial, Managed, Defined, Quantitatively managed, and Optimizing. Finally, the Organization Dimension has the scales of; Unit Oriented, Business Lines Oriented, Business Group/Division, Inter/ Division/Companies and Open Business.

Ahmed and Capretz present a maturity assessment framework for the business dimension of software product family [33]. To characterize the business domain, the authors focus on important business process activities which they termed "key business factors". The adopted key business factors used in the framework are market orientation, strategic planning, order of entry, brand name strategy, innovation, relationships management, assets management, business vision and financial management. The authors state that these key business factors are based on the literature survey of research in software engineering, software product family, business, organization and technical management. Based on the framework, a software product family business evaluation tool has been designed and implemented. The tool takes the data of key business factors as input, and evaluates the overall business maturity of an organization.

In [32], Ahmed and Capretz present an organizational maturity model of SPLE. In essence, the model assesses the institutionalization of SPLE, which involves integrating or improving the business processes associated with the software product line infrastructure, from the dual perspectives of organizational behavior and management. Likewise, the model assumes that organizational theories, behavior, and management play a critical role in the institutionalization of SPLE within an organization. The framework includes assessment questionnaires and a rating methodology. The objective and design of the questionnaires are to collect information about the SPLE process from the dual perspectives of organizational behavior and management.

3.2.3 What are the existing SPLE transition strategies?

Table 2 shows the transition strategies that were identified in the course of the SLR. It was observed that transition strategies are classified under various different categorizations, often based on a single dimension [15]. We discuss this in more detail below.

Table 2. SPLE Transition Strategy Classifications

Source	Identified Transition Strategies
Bosch [35]	Evolutionary existing products, Evolutionary new products. Revolutionary existing products, Revolutionary new products
Buhne [20]	Reactive, Incremental, Proactive
Krueger [36]	Reactive, Extractive, Proactive
McGregor [37]	Lightweight, Heavyweight
Pohl [11], Boeckle [22]	Big Bang, Incremental, Pilot Project, Tactical
Schmid & Verlage [8]	Incremental, Big Bang

Bosch characterizes product line adoption in two dimensions [35]. First, the organization may prefer an *evolutionary* or a *revolutionary* adoption process. Second, a distinction is made as to whether the product line is essentially based on *existing products*, or aims to develop *new products* or a new product family. Based on these two dimensions, four different categories are defined: *evolutionary existing products*, *evolutionary new products*, *revolutionary existing products* and *revolutionary new products*. Each category has an associated risk level and benefits. Bosch further discusses the selection of these approaches based on maturity levels of the organization, the application domain and the product-line artifacts. He argues that these maturity levels and approaches cannot be combined arbitrarily, claiming there are certain combinations which work well together, while others do not.

Likewise, the product-line approaches are related to the artifact maturity levels and organizational models, giving insight as to the combinations that would work for different scenarios.

Bühne et al. [20] claim that the existing literature on transition strategies does not explicitly consider the role of the context in which product line adoption takes place. As such, it is difficult to assess the influence that context can and should have on the transition strategy, and consequently, on the success or failure of the adoption effort. Based on this conclusion, they explore the context for product line adoption at multiple levels, including *market, organization, business unit,* and *individual.* Further, they describe how the characterization of the different levels of the context could be helpful in choosing an appropriate product line approach.

Krueger [36] distinguishes adoption models among *proactive*, *reactive*, and *extractive* strategies. In the *proactive strategy,* an exhaustive study on the product scope is carried out. The commonalities/variations of all of the products are analyzed, architected, designed, and implemented prior to product development. This proactive approach can be applied by organizations that can predict their future product line requirements well and that have the time and resources for a long waterfall development cycle. In the *reactive strategy* only one or several product variations are analyzed, architected, designed, and implemented on each development cycle. Incremental adoption is less expensive in comparison to the proactive approach, and provides quicker results. The reactive approach would work in situations where the requirements for product variations cannot be predicted, or where organizations must maintain aggressive production schedules with few additional resources during the transition to a product line [36]. Another strategy is the *extractive approach,* where one or more existing software products are selected to define the initial basis for the product line. This strategy leads to quick adoption since existing software is re-used as the platform. It seems to be suitable for an organization that desires quick transition from conventional engineering to software product line engineering. These three alternative strategies are not mutually exclusive and can be utilized together for a better way of transitioning. For example, the organization can initiate with the extractive approach and incrementally evolve by using the reactive strategy throughout its product development process.

McGregor et al. [37] distinguish between *heavyweight* and *lightweight* transitions. They define three key ideas to successful product-line efforts: exploring commonality and variability among products, encouraging architecture-centric development, and having a two-tiered organizational structure. For each of these categories, the advantages and disadvantages of *heavyweight* and *lightweight* transition approaches are compared. Regarding costs, the authors state that with heavyweight strategies, a product line's initial product cost is significantly higher than an initial product in single-system development. Hereby it is assumed that after approximately three products, the product line has lower cumulative costs. Further they state that lightweight strategies require minimal upfront investment, which should fall somewhere between the single-product cost and heavyweight cost.

Pohl et al. [11] and Boeckle et al. [22] categorize transition strategies as *Incremental Introduction, Tactical Approach, Pilot Project Strategy,* and *Big Bang Strategy* according to the different business objectives of the companies. In *Incremental Introduction*, product line engineering is initiated as a small entity in the company and is incrementally expanded in terms of organizational and/or investment scope. For the former, a small group starts performing product line engineering, and after their success, more groups are adapted incrementally. For the latter, a small investment is made and the amount is increased incrementally along with the achievements. The *Tactical Approach* is more appropriate when architects and engineers drive the software product line engineering process. The adaptations are carried out only in specific sub-processes such as change and configuration management for multiple related products. The product management sub-process can be triggered after a short and informal initial phase, and hence the outcomes can be measurable and predictable for future development plans. The *Pilot Project Strategy* involves the development of a pilot project before the real, actual product line engineering effort. There are several alternatives for the developed product in the pilot project. The pilot product can be developed as a potential first member of the product line engineering approach. Another alternative is the extension of a set of related products, where the goal is to consider them as the members of a software product line. A toy product can also be developed in the pilot project since the risk and cost of developing such a toy product is relatively small. However, the toy product has to be sufficiently close to the products of the company to forecast the adoption process for the real products. Another alternative is developing a prototype as a pilot project, since the rules are less strict for prototypes when compared to real products. In all of the alternatives, the development activities of the pilot project have to be planned and the outcomes have to be considered to measure the success of the pilot project. Finally, the *Big Bang Strategy* software product line engineering is adopted for the new products of the organization at once. This implies the complete development of the domain engineering process first and building the platform, which is followed by the application engineering process and the realization of the reusable platform.

Schmid and Verlage [8] distinguish between a *big bang approach* and an *incremental approach*, and describe the economic impact of these product line transition strategies, or *adoption schemes* as they call it. The authors discuss the importance of start states of the organizations in selecting a transition strategy. They categorize the state of the organization prior to the adoption as: *Independent, Project-integrating, Reengineering-driven* and *Leveraged*. *Independent* state defines the case in which the company does not have any products yet and the product line will start from scratch. *Project-Integration* indicates that the company already has existing products that have some commonalities, but they are usually separately developed. *Reengineering-driven* indicates that the company already has existing products similar to project-integrating however these products are legacy products, and either they are not suitable for reuse, or it takes substantial reengineering effort to integrate these in the product line engineering context. *Leveraged* indicates that the company introduces a new product line based on a product line that is already in place. According to the authors the start state of the company is the key to selecting transition strategy. The state would have a strong influence not only for the selection of the transition strategy but also for the investment patterns and the expected return on investment. For example in an organization where the start state is defined to be project-integration in which already several products exists, putting product development on hold to focus on developing an integrated product line infrastructure is out of the question. Under these circumstances, selecting an incremental approach is inevitable.

3.2.4 What are the aspects that impact decision making in SPLE adoption?

Each of the identified approaches of the previous sub-section describes a set of aspects that need to be considered to assess the adoption of SPLE for an organization. We have listed and categorized the identified aspects in Table 3 through to Table 6. As discussed above in Sec. 2.3, the categorization is based on the four distinct *dimensions* (Business, Architecture, Process and Organization (BAPO) of the Family Evaluation Framework [16]. Each dimension includes an evaluation scale that is used to assess the organization. The overall evaluation will result in a profile of an organization in which the values for the four dimensions are given and explained. As can be seen in Table 3 through to Table 6, we have identified 25 different aspects from the SLR. In the tables we briefly describe the impact of each aspect and describe the correlation of the aspect with respect to SPLE feasibility and the selection strategy. Each aspect can be either positively or negatively correlated with SPLE adoption. A positive correlation implies an increase of the aspect value will lead to an increased positive decision on SPLE adoption. For example, the market potential aspect is positively correlated with SPLE feasibility. On the other hand, the required investment will impede the decision on SPLE adoption and as such be negatively correlated. Some aspects can be either positively or negatively correlated depending on the context of the decision. It appears that most of the aspects that impact the decision on SPLE adoption also have an impact on the strategy selection. This is shown in the right hand column of the tables. For example, where the business motivation is low, this will impede the selection of heavyweight strategies.

Table 3. Aspects that impact the SPLE Adoption Decision (Business Dimension)

Aspect	**Impact on SPLE Adoption Decision**	**Impact on SPLE Transition Strategy Selection**
Business Motivation [30][33][32][22][20][38][39][40][41][42][43][11][8][44][45][15][10][9][46][21][23]	The main business motivation includes high-level business goals such as time-to-market, cost of development and increasing quality. A higher business motivation will positively support SPLE adoption.	A weak business motivation impedes the adoption of heavyweight strategies.
Connection With Customers [33][22][20][41][47][11][45][48][23]	Connection with customers defines the ability to interact with and understand the customers' needs. Close relationship with customers will positively support the SPLE adoption because it will ease the scoping, development and evolution of SPLE adoption.	No explicit correlation could be found with SPLE transition strategy selection.

Aspect	Impact on SPLE Adoption Decision	Impact on SPLE Transition Strategy Selection
Degree of Control over Product Specification [30][33][20][39][41][10][23]	The degree of control over product specification describes the freedom of the company to define the product line. A low degree of control implies that the customer has a strong impact on product definition and as such the variability will be hindered. This will decrease the adoptability of SPLE.	Where the customer has too much control on the product line, a heavyweight or proactive approach would be less feasible. Otherwise, the other aspects are used to select a feasible transition strategy.
Expected ROI [33][22][38][39][49][40][37][41][43][11][8][45][10][23]	Return-on-investment (ROI) measures the benefits with respect to the provided up-front investment. A higher expected ROI will positively support adoption of SPLE.	Long term gains usually require heavyweight strategies and maximize the expected ROI. Short term gains would require lightweight strategies.
Funding Source Stability [20][10][23][22][40][47][42]	Stable funding is needed to prepare and support the organization for a product line approach. A stable funding source will positively support and ease the SPLE adoption decision.	Higher funding stability is correlated with heavyweight approaches; lower funding stability will imply lightweight strategies.
Market Potential [30][33][32][20][49][41][11][50][8][45][10][23][36]	The market potential is the estimated maximum total sales revenue of the product types in the product line. Market potential positively supports the adoption of SPLE.	No explicit correlation could be found with SPLE transition strategy selection.
Potential upfront investment [22][38][47][8][45][51][48][23][36]	For starting SPLE upfront investment is needed. The potential upfront investment that the company can provide can determine the decision for SPLE adoption.	In cases where the potential upfront investment is high, then heavyweight strategies can be adopted; otherwise more lightweight strategies need to be selected.
Potential overall Investment [22][20][52][38][49][41][47][42][43][8][45][51][10][9][36]	Besides the company's potential for upfront investment the potential for the total investment of the SPLE approach will determine the decision for SPLE adoption.	Where the potential overall investment is high, then heavyweight strategies can be adopted to reduce the costs over the long-term period. Otherwise more lightweight strategies need to be selected.
Risk Tolerance [22][38][42][43][11][50][8] [10][23][36]	SPLE adoption is not trivial and involves several risks that can lead to failure of the SPLE. A higher risk tolerance will positively impact SPLE adoption.	If the risk tolerance of the organization is low, then heavyweight approaches are not feasible.
Degree of Globalization [22][23]	Globalization here refers to the internationalization or localization to provide and sell a software product around the world. The degree of globalization increases the scope of the product line, and hence supports the adoption of SPLE.	No explicit correlation could be found with SPLE transition strategy selection.

Table 4. Aspects that impact the SPLE Adoption Decision (Architecture Dimension)

Aspect	Impact on SPLE Adoption Decision	Impact on SPLE Transition Strategy Selection
Clearly Defined Scope [22][20][39][49][41][42][43][50][8][45][10][23][36]	Scoping is the process of determining the boundaries of the product line engineering activity. A high degree of clearly defined scope is desired for SPLE feasibility.	For a heavyweight strategy such as Big-Bang strategy, the scope of the product line needs to be clearly determined.
Commonality and Variability of Products [30][33][53][35][20][49][31][37][41][42][43][11][44][50][8][10][9][48][9][21]	To define a reusable asset base it is important that the products in the product line have balanced level of commonality and variability. The combination of these will define the suitability of SPLE. High variability and thus low commonality will increase the cost of application engineering. Low variability and high commonality will reduce the scope of the product line and the market share.	No explicit correlation could be found with SPLE transition strategy selection.
Domain Knowledge [30][33][35][22][20][38][39][41] [47][43][11][44][50][8][51][15][10][48][23][21]	The depth of understanding that has been achieved in a domain for which applications are developed. Obviously the better the domain is managed the easier it is to support the SPLE activities.	If the level of domain knowledge is low, then more exploratory strategies such as pilot project strategy are recommended. A strong domain knowledge supports the selection of heavyweight strategies.
Domain Stability [30][35][20][39][11][44][50][8][15][10][23]	Domain stability refers to the degree to which we can expect the domains relevant to the product line to change in the foreseeable future. In general, the more stable a domain is, the easier it will be to adopt SPLE.	If the domain is instable the feasibility of SPLE is low and hence no specific transition strategy is proposed. In the case of stable domain the other aspects are used to define a suitable strategy.
Existing Core Assets [30][22][20][49][37][43][44][50][8][45][10][48][23][21]	The amount of existing core assets from similar projects can help to launch the SPLE.	Existing assets support the selection of extractive transition strategies in which the existing assets are adopted as core assets. The lack of existing assets requires the selection of either proactive or reactive transition strategies.
Software Architecture Competence [22][20][38][39][49][31][37][41][47][44][51][10][48][23][21][36]	Software architecture competence is the ability of the organization to acquire, use, and sustain the skills and knowledge necessary to carry out software architecture-centric practices. Since product line architecture is one of the most important core assets the architecture competence will have a positive impact on the SPLE adoption decision.	Software architecture is an essential aspect for adopting SPLE. If software architecture competence is too low then it is recommended that this should be enhanced first. In case of a strong software architecture competence, then the other aspects are used to select a suitable strategy.
Ratio of Software [30][41][44]	The percentage of software in the overall product.	No explicit correlation could be found with SPLE transition strategy selection.

Aspect	Impact on SPLE Adoption Decision	Impact on SPLE Transition Strategy Selection
Technological Stability [30][41][43][23]	Products in the product line typically include various technologies. A stable technology will support the proper product lines scoping and as such, help the SPLE adoption.	If the required technology is instable the feasibility of SPLE is low, hence no specific transition strategy is proposed. In the case of stable technology, the other aspects are used to define a suitable strategy.

Table 5. Aspects that impact the SPLE Adoption Decision (Process Dimension)

Aspect	Impact on SPLE Adoption Decision	Impact on SPLE Transition Strategy Selection
Process Maturity [32][22][20][38][54][55][39][31][47][42][43][11][44][50][15][10][48][23][21]	The term "process maturity" relates to the degree of formality and optimization of processes, from ad hoc practices to formally defined steps, managed result metrics, and active optimization of the processes A higher process maturity is required for SPLE feasibility.	The lack of process maturity can lead to selection of tactical transition strategies. The more mature processes can use the other strategies.
Tool Support [22][20][38][39][47][43][11][10][48][23][36]	Available tool support for supporting the activities in the SPLE two lifecycle process that will support the SPLE adoption.	No explicit correlation could be found with SPLE transition strategy selection.

Table 6. Aspects that impact the SPLE Adoption Decision (Organization Dimension)

Aspect	Impact on SPLE Adoption Decision	Impact on SPLE Transition Strategy Selection
Human Resources Available [33][32][22][20][52][38][39][49][42][43][50][8][10][48][23][36]	For conducting the SPLE approach, the required human resources need to be available. Any lack of human resources will negatively impact the SPLE adoption.	In cases where the required human resources are not available, then the heavyweight approaches are not recommended. If the human resources level is sufficient, then other aspects are used to define a suitable strategy.
Management Support [33][32][22][20][52][38][39][49][31][47][42][43][11][44][45][10][48][23][21]	The degree of management support for SPLE adoption. Higher levels of management support (e.g. support of the CEO) would increase the chance of SPLE feasibility	If the management support is high, heavyweight approaches are more feasible. If the management support is low(er), then the organization may choose a lightweight strategy (pilot, tactical, incremental)
Organizational Disruption [22][38][49][47][43][45][51][23][36]	The adoption of SPLE usually has an impact on the organizational structure. Based on the acceptable level of organizational disruption, the adoption of the SPLE feasibility can be decided.	Where the desired organizational disruption is low, then the selection of lightweight strategies will be preferred. In cases where a high organizational disruption can be afforded, the selection of heavyweight strategies can be selected.
Organizational Stability [32][35][22][20][52][38][37][42][50][10][48][23]	Organizational stability refers to the ability of an organization to cope with any major disruptions and unexpected changes in the external environment, or turnover of personnel. For adopting SPLE it is important that the organization itself is stable.	If the organizational stability is low, then the feasibility of SPLE is low and hence no specific transition strategy is proposed. In the case of high organizational stability, the other aspects are used to define a suitable strategy.
SPLE Knowledge [32][22][20][52][38][39][49][31][47][42][43][51][10][48][23][21][44]	The knowledge and understanding of Software Product Line Engineering in the organization will directly support the SPLE adoption.	If the SPLE knowledge is low then the adoption of heavyweight approaches are not advised. In case of a strong SPLE knowledge the other aspects are used to select a feasible strategy.

3.2.5 What are the questions and rules regarding the decision-making process for SPLE adoption?

The process for systematically identifying and describing the questions and rules is depicted in the activity diagram in Figure 7. The process starts with selecting the primary studies from which we can extract the questions, possible answers and the rules. The activity *Extract Questions* implies the detailed analysis of the given primary study and the identification and description of the described questions that impact the decision-making process. The activity *Extract Rules* aims to identify the rules based on the selected questions. Following these activities the possible answers and action rules are defined. In our study, the questions and rules were identified separately by the three researchers. After each author had defined the questions, the rules and the corresponding answers and action rules, their results were consolidated; which led to the final set of questions and rules. In case of inconsistencies among the results, the primary study was repeat analyzed until a final decision could be made. After the selection of the questions and rules, these were categorized into the BAPO dimensions.

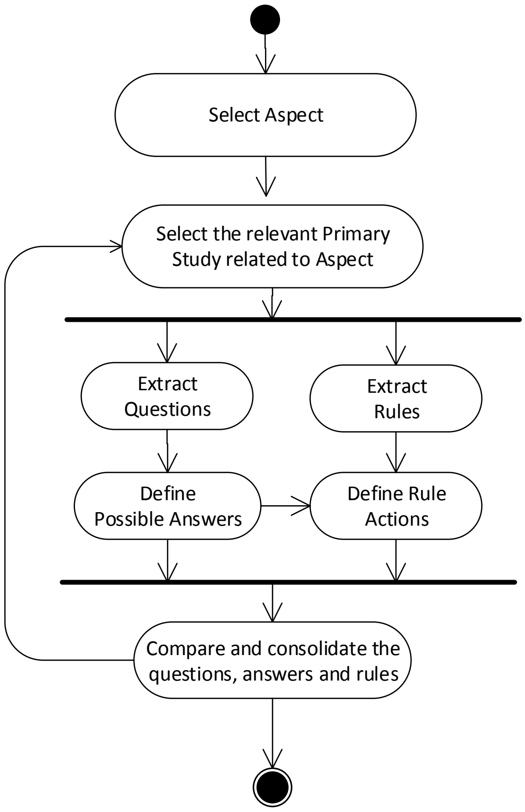

Figure 7. Process for extracting questions, answers and rules based on derived aspects

We have defined the question template in Table 7 that can be used to collect and store the questions to be used in the decision-making process. Each question will have a question type including general question, feasibility question or strategy question. As stated before, feasibility questions and strategy questions will require an answer that will have an impact on the decision-making process. Each question will have one or more possible answers.

Table 7. Question template for decision-making process

Question Element	**Description**
Question ID	Presents a unique identifier to distinguish the different questions.
Description	Short explanation of the question.
SPLE Dimension	Defines for which dimensions of *Business*, *Architecture*, *Process* and *Organization* the question applies.
Aspect	Defines the aspect in the selected dimension that will be assessed using the question.
Source	Links to sources from which the questions, the possible answers, and the rules have been derived.
Question Type	Defines whether the question is a *general question*, *feasibility question*, or *strategy* related question.
Possible Answers	Describes the expected answers and the required format to the question.

Table 8 shows for example, the descriptions for question Q37 based on the template in Table 7. The feasibility and strategy questions were derived from the SLR, whereas the general type questions added for the purpose of collecting more information about the company. The complete set of questions that are present in *Transit-PL* are listed in Appendix B.

Table 8. Example Description of Question

Question Element	**Description**		
Question ID	Q37		
Description	To which extent is the product line scope defined?		
SPLE Dimension	Architecture		
Aspect	Clearly Defined Scope		
Source	[22][20][39][49][41][42] [43][50][8][45][10][23][36]		
Question Type	Feasibility, Strategy		
Possible Answers	We have a well-defined product portfolio and roadmap.	The product portfolio is largely known but not committed yet.	The product portfolio is not determined yet. This should still be decided.

In a decision support system, the answers to the questions are used to provide a decision. The decisions are defined based on the execution of rules. Similar to the questions and the potential answers, the rules have also been identified in the data extraction process of the SLR. For this, we have used the generic rule template as defined in decision support systems.

IF <Condition> THEN <Action>

Hereby, <*Condition*> refers to the values of the aspects that are assessed with the corresponding questions. The <*Action*> part generates the feedback and defines the score for the feasibility and the strategy. In our current system we have defined 312 rules. An example rule is shown in Table 9. In this table, we have set of rule elements and corresponding descriptions. The rule has an ID, for identification purposes. All the rules are linked to question ID, and a corresponding answer. Based on question ID, answer pair, rule actions are defined in the feedback row.

Table 9. Example Rule for SPLE Feasibility

Rule Element	Description
Rule ID	R29
Related Question	Q31
Question Text	What is the CMMI maturity level of the organization?
Answer	CMMI 2
Feedback	Feasibility Risk: Maturity level 2 generally represents institutionalization at the project level. Because the SPL requires coordination across projects (organizational level), it still requires higher levels such as CMMI Level 3 to perform successful SPL transition. Feasibility Recommendation: In order for a successful SPL transition, CMMI Level 3 is recommended. Suggested Strategies: A higher process maturity especially supports the adoption of heavyweight strategies. The lack of process maturity can lead to selection of tactical transition strategies. The more mature processes can use the other strategies.

The complete list of rules can be accessed in the predefined decision plan at http://transitpl.herokuapp.com.

3.3 Threats to Validity of the SLR

The findings from the SLR could have possibly suffered from several validity threats. Below we describe the potential threats and briefly discuss our mitigation strategy for each threat.

Construct validity refers to the degree to which the SLR measures what it aims to be measuring. One possible threat to construct validity is the exclusion of relevant studies. In order to minimize this threat, we applied detailed guidelines of systematic literature review protocol and defined a rigorous search strategy. We also searched company journals, grey literature, conference proceedings and the internet, which led us to new papers not identified in our regular search. We performed the inclusion/exclusion procedures on a well-established screening of primary studies. We included both qualitative and quantitative studies in almost all respects. For reducing the selection bias for deciding on the primary studies, the evaluation and selection were performed separately by three researchers. Each researcher recorded their reasons for acceptance or rejection for all the studies under consideration. Later on, all the researchers' lists of evaluated primary studies were compared and any differences were discussed in detail in order to arrive at a mutually acceptable final decision.

After the primary studies were evaluated, the relevant data was selected, that is, the questions and rules extracted. To ensure the outcome validity of the data extraction process, we had to address three main questions:

> (1) Were we able to extract all the aspects, questions and rules from the literature successfully? (Completeness);
>
> (2) Did we come up with valid aspect, question & rule pairs? (Correctness);
>
> (3) Were all the aspects, questions & rules necessary? (Non-redundancy).

We tried to deal with these questions in our review in several ways. First of all, we defined a clear data model which clearly identified the data items that should be extracted. The data model was largely based on the model as depicted in Figure 8. Based on the data model we first checked the data extraction process by considering a randomly selected set of papers. Later on, each of the three reviewers extracted and analyzed the data (i.e. aspects, questions, rules and answers) from the primary studies. The data extraction results were included in MS Excel spreadsheets with the description of the identified data elements (aspect, question, rule, answer), as well as the source of the data elements. The results were then discussed among the three researchers, and all discrepancies settled to ensure the extraction was as objective as possible. In this process we observed that some papers lacked sufficient details to extract all the required data. For example, sometimes the addressed aspect was mentioned, but the related questions were not described, or questions were defined, but the expected answers were not precisely described. Hence, sometimes it was necessary to infer certain pieces of information during the data extraction process. To minimize our own bias, this was done by considering the results of the selected primary studies in which the data elements were mentioned. Despite careful consideration and discussion, there remains the possibility that the data extraction process might have introduced slight inaccuracies to the extracted data.

Internal validity threat entails the possibility of establishing an invalid causal relationship based on the findings. In the context of the present study, the SLR was essentially exploratory, aiming to determine the aspects, questions and rules of the SPLE feasibility analysis and transition decision. Hence, it was sufficient to ensure that their relevance was ascertained in the investigated literature.

Conclusion validity (reliability) is the degree to which conclusions about the relationship among variables based on the data are correct or reasonable. This threat is mitigated by adopting a clear SLR protocol, including well-defined steps and the involvement of four researchers. The outcome of the SLR is quite broad and if the study would be replicated by different set of researchers, it is possible that the final set of selected primary studies could be slightly different. However, the general findings related to the identification of aspects, questions and rules would be quite similar. As such, we believe that the conclusion validity of the SLR is high, given the use of a very systematic procedure and the involvement of four researchers and the ensuing discussions. In the following sections, we even further elaborate on this by discussing the case study design research.

External validity refers to the extent to which the results of the SLR can be generalized outside the scope of the study. Within the context of our study, we can relate this to the degree to which the primary studies and the extracted data elements are representative of the overall goal of the review. This risk is largely mitigated by the detailed and careful review protocol discussed above.

3.4 Related Work

Bastos et al. [38] present the results of a systematic mapping study to analyze the important aspects that should be considered when adopting SPL approaches. They selected and evaluated 34 primary studies from which they identified the basic SPLE adoption strategies and list the important adoption barriers. They conclude that there is insufficient information on linking strategies to factors, such as organizational structure and process maturity, and state that there is a need for patterns to assist in SPL adoption and overcoming SPL adoption barriers. We carried out a comprehensive SLR, rather than a mapping study, for both SPLE feasibility and the selection of SPLE strategies. Based on the data extraction of the selected primary studies, we have identified and described the important aspects of SPLE feasibility and strategy selection, as well as the corresponding questions and rules. As such, we provide explicit and systematic assistance for SPLE adoption to overcome the important barriers and mitigate the risks.

As stated in various SLRs on SPLE, empirical evaluation requires more attention. Ahnassay et al. [56] present a systematic review that focuses explicitly on depicting the empirical evaluations undertaken in SPLE. They carried out a systematic literature review of the software product line methods, techniques, and approaches reported from January 1, 2006 through to December 31, 2011. The results of the SLR revealed a significant number of evaluations conducted in academia, with only 25 studies conducted in an industrial setting. However, the majority of the evaluations did not use industrial sized examples. The authors conclude that a large majority of evaluations had not been sufficiently designed or reported.

Schmid et al. [57] provide a comparative analysis of decision modeling approaches in product lines. The authors focus on approaches that explicitly relate to decision modeling and variability management in SPLE. They discuss and compare five different approaches for each, for which they provide a short overview of its characteristics and the underlying concepts. In our study, decision modeling relates to the support for adopting SPLE and does not consider decision modeling within the context of variability modeling approaches.

Bagheri et al. [58][59] present a decision support platform to help the analysts throughout the domain engineering lifecycle. The focus is in particular on supporting the decisions for selecting the common and variant features that need to be incorporated in the feature models. The decision support platform is not a decision support system in the strict sense, but a structured information extraction tool that identifies important pieces of information from domain documents. The system highlights information from the text and provides additional visualization and ontological representation to support the domain analysts in the decision-making process.

Chapter 4

DECISION SUPPORT MODEL for SPLE ADOPTION

Based on the data extraction and synthesis activities of the SLR, we have constructed a Decision Support Model. In the proposed DSM, as shown in Figure 8, the *Scheduler* schedules and presents a number of *questions* to the decision-maker. Questions are based on *Evaluation Aspects* such that each focus on a different aspect in the decision-making. Question can be *General Question*, *Feasibility Question* or *Strategy Question*. A general question aims to extract information about the company (e.g. name and size of the company) that does not impact the selection of the decision-making process. SPLE feasibility questions aims to check whether it is feasible at all to transition to SPLE. Finally, the questions related to strategy aim to find the proper SPLE transition strategy. Some questions in the system can be related to both the feasibility of adopting SPLE and the related transition strategy. *Answer* is requested by *Question* and is used by *Rules* to score the decision parameters. The decision parameters are *SPLE Feasibility* and *Transition Strategy*. The *Scheduler* uses the results of the rules to derive a final conclusion.

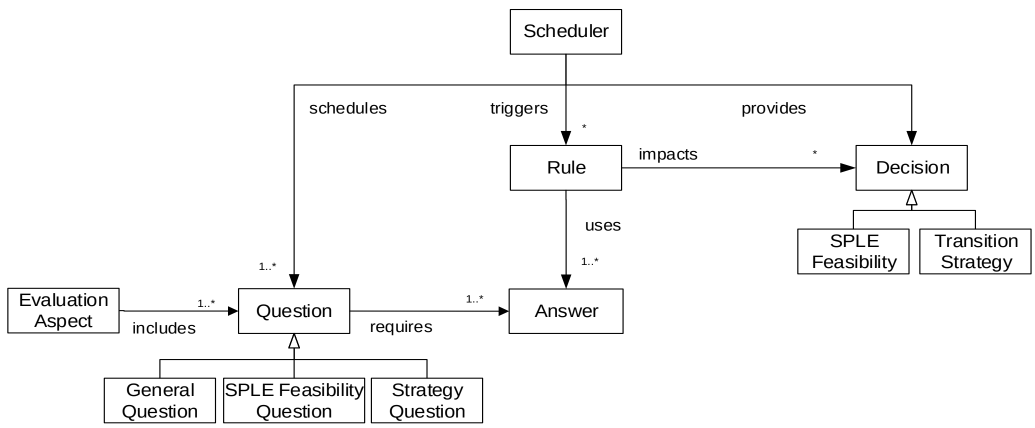

Figure 8. Decision Support Model for adopting SPLE and the selected strategy

To support the feasibility analysis and transitions strategy selection process, it is worthwhile to develop a decision support system that implements the proposed DSM for selecting and motivating the proper transition strategy. The tool *Transit-PL* [18] has been developed to provide the basis for the empirical research that has been applied to verify applicability of the constructed DSM.

The rest of the section is organized as follows: In Section 4.1 we provide a brief introduction on Decision Support Systems, and in Section 4.2 we present the overall architecture of this tool. Section 4.3 discusses the process for configuration of the tool, Section 4.4 provides an example configuration, and Section 4.5 describes the usage of this tool.

4.1 Decision Support Systems

A decision support system (DSS) is a computer-based information system that supports business or organizational decision-making activities. DSSs serve different layers of management help making decisions, which are usually unstructured in nature and not easily specified in advance [60][61][62]. DSSs include knowledge-based interactive systems that can support decision-makers in compiling useful information from a combination of raw data, documents, and personal knowledge to identify and solve problems and make decisions [60]. As shown in Figure 9, a DSS typically consists of a UI component, knowledge base and an inference engine.

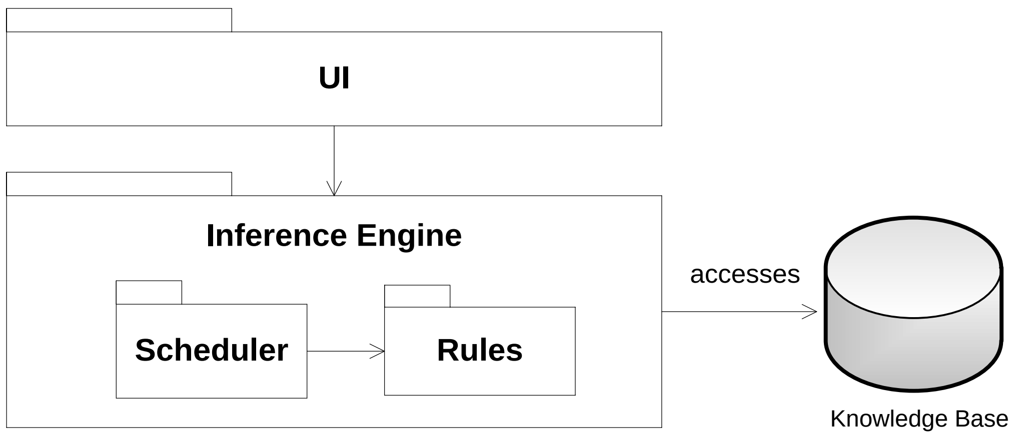

Figure 9. Conceptual Decision Support Architecture

The UI is used to interact with the inference engine. The global knowledge base consists of facts that are used by the inference engine to derive a decision. The inference engine itself consists of *production rules* and *scheduler* for determining the order in which the rules are triggered.

DSSs can be categorized in different ways based on different criteria. In [61], a classification is provided that adopts the *relationship with the user* as the key criterion, and likewise differentiates *passive*, *active*, and *cooperative* DSS. A passive DSS is a system that aids the process of decision-making, but that cannot bring out explicit decision suggestions or solutions. An active DSS can bring out such decision suggestions or solutions. A cooperative DSS allows the decision-maker (or its advisor) to modify, complete, or refine the decision suggestions provided by the system, before sending them back to the system for validation. The system again improves, completes, and refines the suggestions of the decision-maker and sends them back to him for validation. The whole process then starts over again, until a consolidated solution is generated.

Based on the *mode of assistance* criterion, Power [60] distinguishes between *communication-driven, data-driven, document-driven, knowledge-driven,* and *model-driven.* A communication-driven DSS supports more than one person working on a shared task. A data-driven DSS emphasizes access to, and the manipulation of, a time series of data, internal or external to the company. A document-driven DSS manages, retrieves, and manipulates unstructured information in a variety of electronic formats. A knowledge-driven DSS provides specialized problem-solving expertise stored as facts, rules, procedures, or in similar structures. A model-driven DSS emphasizes access to and manipulation of a statistical, financial, optimization, or simulation model. Using *scope* as the criterion, Power makes a distinction among *enterprise-wide DSS* and *desktop DSS*. An enterprise-wide DSS is linked to large data warehouses and serves many managers in the company. A desktop, single-user DSS is a small system that runs on an individual manager's PC.

In this research, *Transit-PL* is implemented as a dedicated tool for SPLE feasibility analysis and strategy selection. *Transit-PL* can be characterized as an active and cooperative DSS. It helps the SPLE manager to provide a decision on the feasibility of adoption of SPLE and the selected transition strategies. Further, *Transit-PL* is a knowledge-driven DSS, since it stores and accesses questions, answers to questions, and the related rules, in order to provide a decision. Finally, we categorize *Transit-PL* as an enterprise DSS, since it is a web-based system that can be accessed and used by many different managers.

4.2 Transit-PL Architecture

Figure 10 shows the conceptual architecture of *Transit-PL*, the DSS that we have developed based on the earlier defined DSM, and using the output of the SLR. *Transit-PL*[2] has been implemented as a web-based tool and made freely available. The tool has been developed using Ruby on the server-side and AngularJS[3] on the client-side, and deployed to Heroku[4] cloud application platform.

Transit-PL has been developed according to the general architecture as defined in the literature on DSSs. As it is shown in Figure 10, the decision-maker interacts with the system through a user interface to provide the requested information, and to retrieve the intermediate and final recommendations for making a decision. The inference engine is used to reason

[2] http://transitpl.herokuapp.com
[3] http://www.angularjs.org
[4] www.heroku.com

with the rules derived from the systematic literature review and the case specific data, which includes both the information entered by the decision-maker and the partial conclusions based on this data. The reporting and explanation module is used to provide the intermediate explanations and the final report.

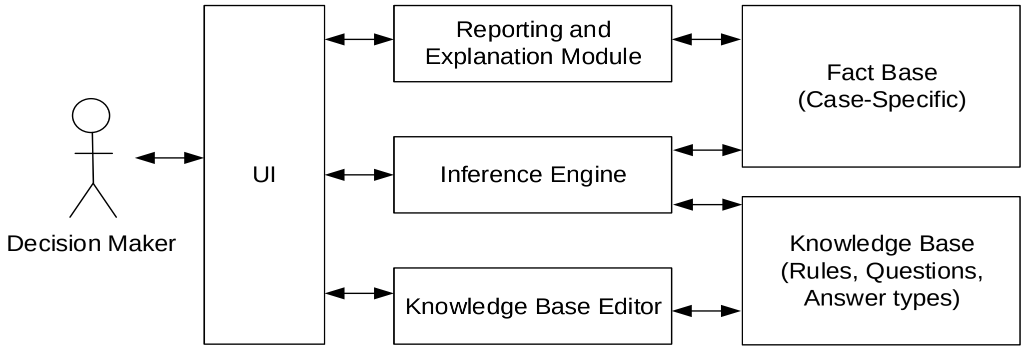

Figure 10. *Transit-PL* Architecture

The tool can be used both by *decision support designer* and *decision-makers*. Decision support designers can use the toolset to define and configure a *decision support process*. Each decision support process can be stored (in JSON file format) and made publicly available in the tool, which enables a more rigorous validation throughout various runs and feedbacks. Decision-makers can select and use the defined decision support systems to support the decision on the adoption of SPLE.

4.3 Configuration of Transit-PL

For using *Transit-PL*, it is necessary to first configure the Knowledge Base. The workflow for this is shown in Figure 11.

As stated previously, a question may be a type of general, feasibility or strategy-related question. We further distinguish among the following questions, based on the required format of the answers: text-input, numeric-input, single-select and multiple-select. As the name suggests, text-input question gathers a piece of text from the user, and no further configuration is required. Numeric-input can be used to obtain a number; a minimum and maximum value limit for the answer should be specified for this type. Single-select refers to a question with one or more options for which one option is selected. Multiple-select question is the same as single-select, except multiple answer options can be selected.

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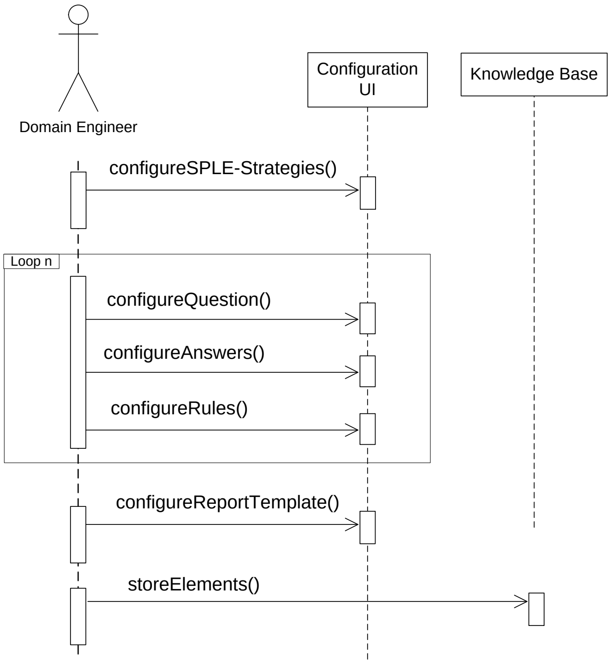


Figure 11. Workflows for Configuring the Knowledge Base

After the definition of questions with possible answers, rules are defined based on the answer set. Rules have conditions determining the action. These elements focus on the impact of an input, answers given to questions, on the transition process and generate helpful suggestions. Each rule is linked to SPLE feasibility or a transition strategy. A rule has the following structure: *if* <*condition*> *then* <*actions*>, in which *condition* becomes true or false according to the given answer that rule applies to, and *actions* refer to a score, and a list of explanations providing reasoning and suggestions for supporting the decision process. Table 10 lists the corresponding conditions for each question type.

Table 10. Question types and corresponding rule conditions

Question Type	**Rule Condition**
Text-input	*has-keyword(word)*
Numeric-input	*in-range(lower, upper)*
Single-select	*in-set({S: S ⊆ A, A is the set of answers})*
Multiple-select	*in-set({S: S ⊆ A, A is the set of answers})*

The function, *has-keyword* checks for a specific word in a text. If the word passed to *has-keyword* function is found in the answer, then the function returns true, otherwise false. The *in-range* function becomes true if the answer to a numeric-input question is in *[lower,* *upper)*, otherwise false. The *in-set(S)* function checks whether the given answer is a subset of set *S*, which can be any subset of all possible answers. The set *S* can be described by combining elements in answer set *A* with logical predicates.

Table 11 provides a list of actions that can be defined within a rule and their explanations.

Table 11. List of rule actions

Rule Actions	**Description**
Likert-scale Score	A Likert-scale value between 1 and 5
Potential Risks	The potential risks that may be faced according to the answer given to the question.
Recommended Step	The step that is recommended to be taken in the transition process.

Once all the questions, possible answers and the corresponding rules are finalized, the *report* that is to be generated will be configured. For this, a *report template* is defined describing the elements that need to be shown in the final report, including strategy descriptions, the questions posed, the descriptions of the questions, the answers that were given, the triggered rules, the risks identified, the overall evaluation and the recommended steps. Each of these can be selected/deselected using checkboxes in the configuration. The report will include the results of the overall feasibility analysis for adopting SPLE, and the SPLE transition strategy selection analysis, based on the answered questions and the triggered rules in the system. Part of the results will be the same for all reports; such as question descriptions and strategy descriptions. The remaining parts will be different for each report with respect to the answers provided and likewise, the different rules triggered. The feasibility for adopting SPLE is separately explained in the first section of the report. The subsequent sections will describe each strategy in detail, including the justification, recommendations and risks for selecting the strategy. In principle, the report will be automatically generated from the text that has been introduced when defining the questions and the rules. The section with the strategies will be based on the defined strategy types. In the case of other defined strategies, the report template is changed accordingly. The report includes both qualitative analysis using the previously provided text, as well as histogram representations that depict the results of the scores for the answers.

4.4 Example Configuration of Transit-PL

In the decision support definition process, first the strategies are defined. Figure 12 shows a snapshot of the tool from which existing predefined decision plans (decision support process) can be downloaded. Each plan is represented with their titles, whether the plan is publicly available or not, the link to the plan, and the actions that can be performed on the plan.

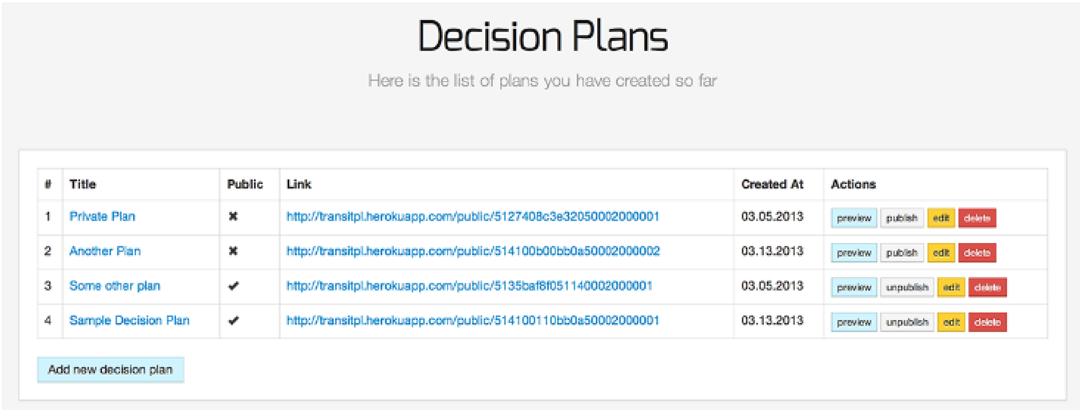


Figure 12. List of decision plans previously created

In case it is chosen to create a new decision support process then the subsequent three steps need to be followed. The first step is to give a name to the plan as shown in Figure 13.

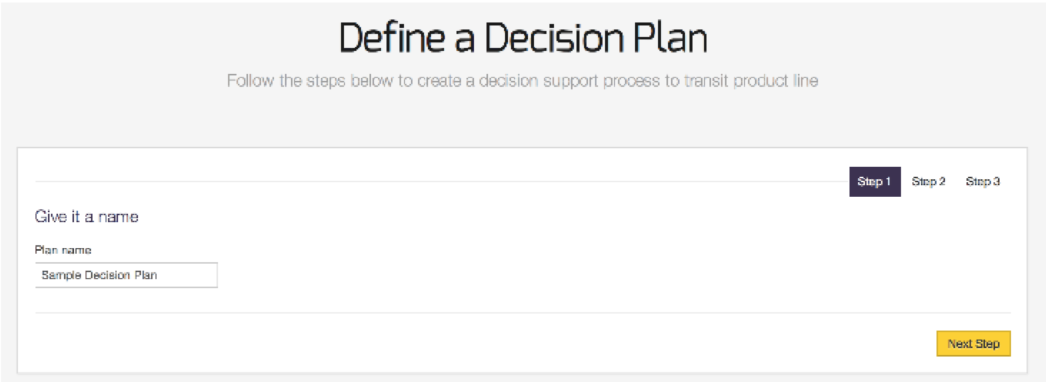


Figure 13. Naming the decision plan

The second step is to create transition strategies. A strategy consists of a name and description. Figure 14 shows a list of strategies and a feasibility condition created for the demo plan.

The final step is to create questions and configure rules using the possible answers for each question. Figure 15 demonstrates a question for the sample plan, which is a single-select question expecting an option to be selected by the user. The question configuration part is followed with a preview showing the live demo for that question configuration, as if it is presented to a user, and below that, a part for rules is shown. This part starts with a description of the question and then each rule created for that question is listed.

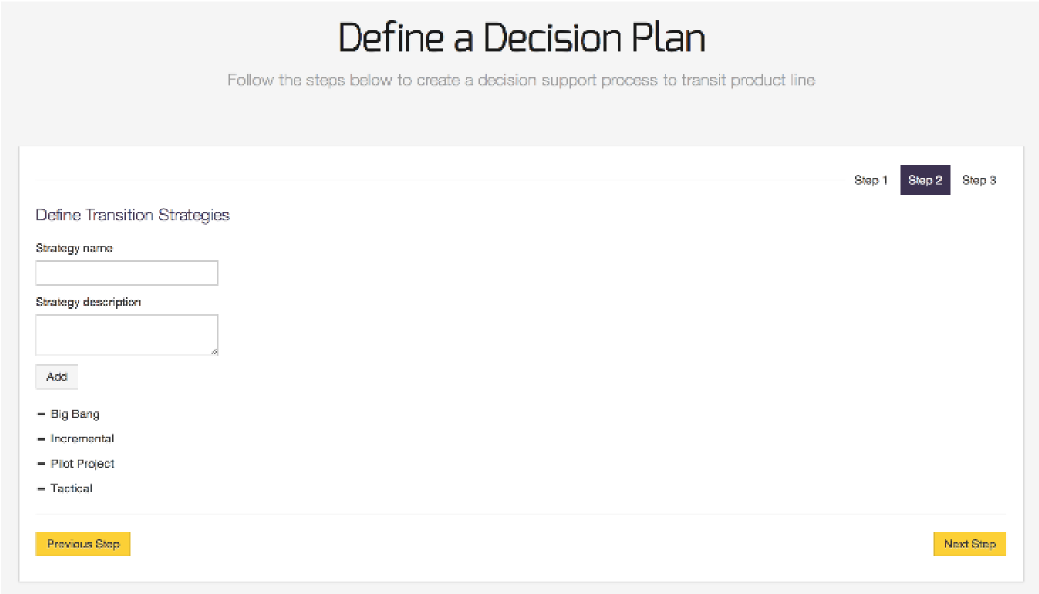


Figure 14. Defining transition strategies for the plan

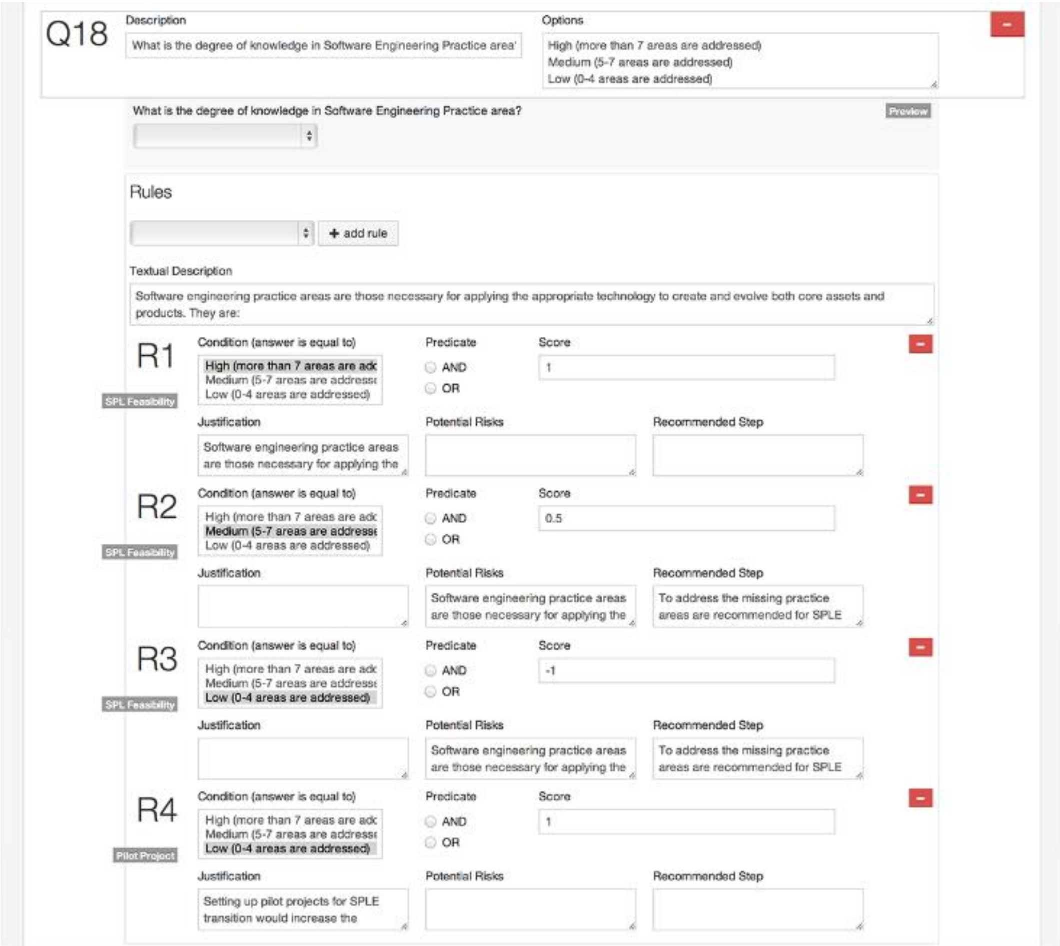


Figure 15. Defining a question with a rule set

Figure 16 shows a list of questions to be answered for which only a small fraction of questions is given due to space limitation. These questions are expected to be defined previously through the decision support process definer and connected with a set of rules. In addition, the sections that are shown on the generated report can be configured using the checkboxes at the bottom. In this way, a decision-maker can create customized reports by including or excluding different sections.

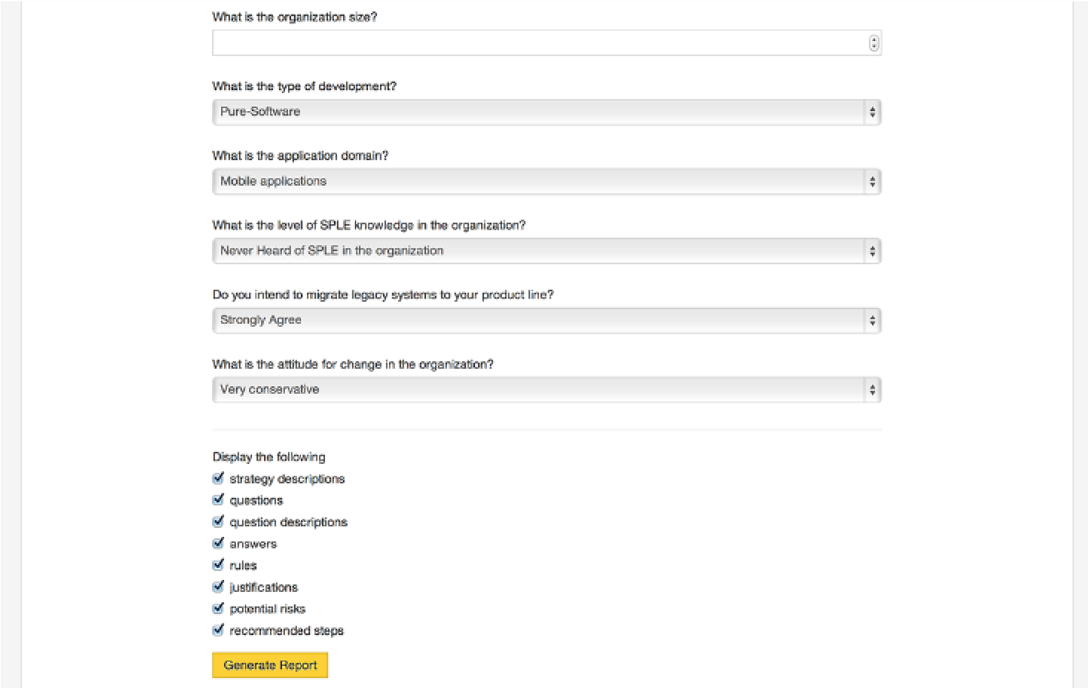


Figure 16. Preview of a decision plan as a questionnaire

4.5 Usage of Transit-PL

Once the Knowledge Base is configured as discussed above, the system will be ready to support the decision-making process for adopting SPLE, and the selection of the SPLE transition strategy. The workflow of the actual decision-making process in *Transit-PL* is shown in Figure 17. The *Scheduler* component starts with selecting the set of questions from the Knowledge Base that have been previously defined, and presents this to the decision-maker to gather answers. The answers of the decision-maker are stored in the Fact Base. The rules retrieved from the Knowledge Base are triggered, and a score for the feasibility and strategy selection values will be provided. After answering the questions and the triggering of the rules, a report will be generated that contains the predefined questions, the answers entered, and the activated rules together with the predefined risk and recommendations.

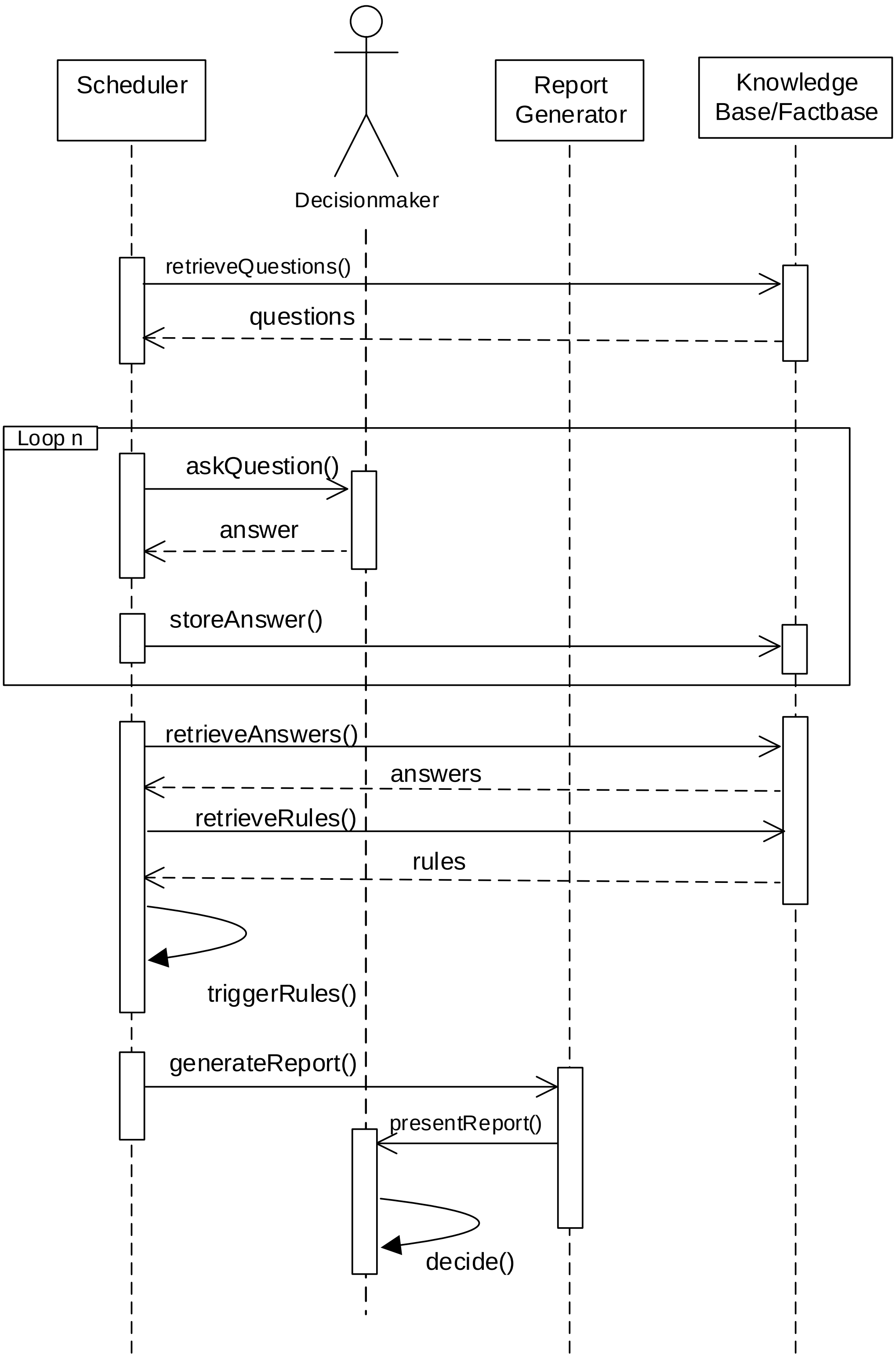


Figure 17. Workflow for Execution of the Decision-making Process in *Transit-PL*

Figure 18 shows, for example, a list of questions to be answered.

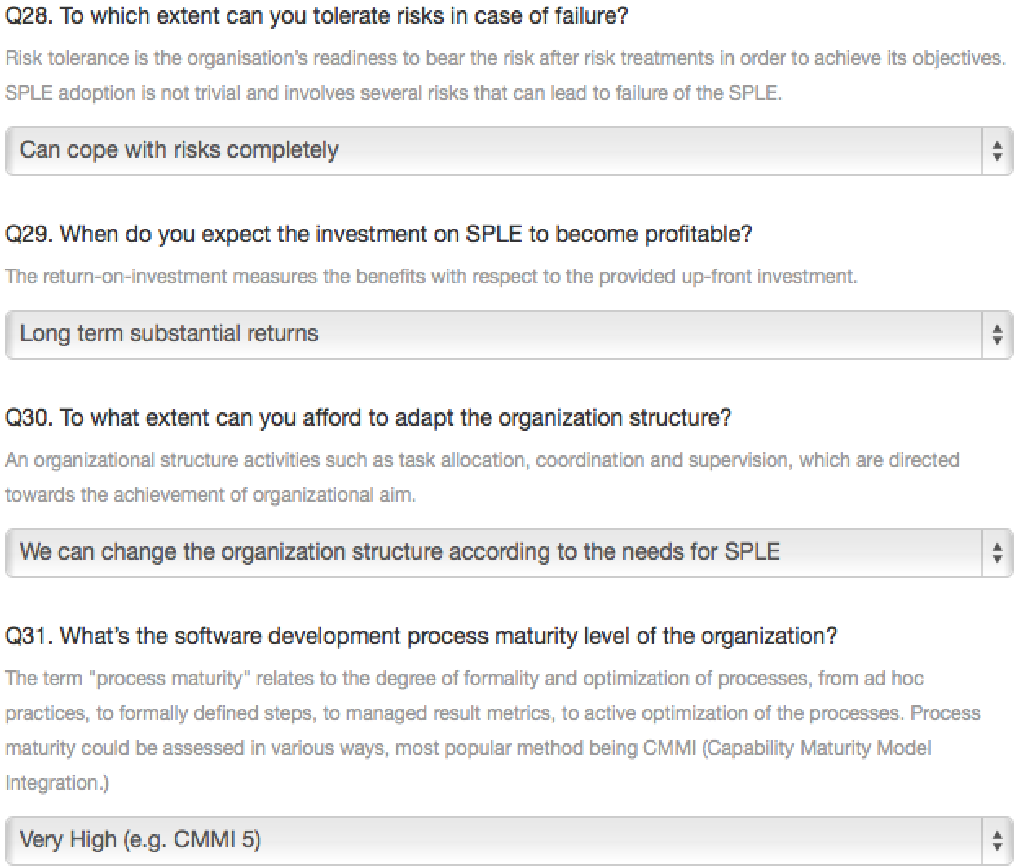
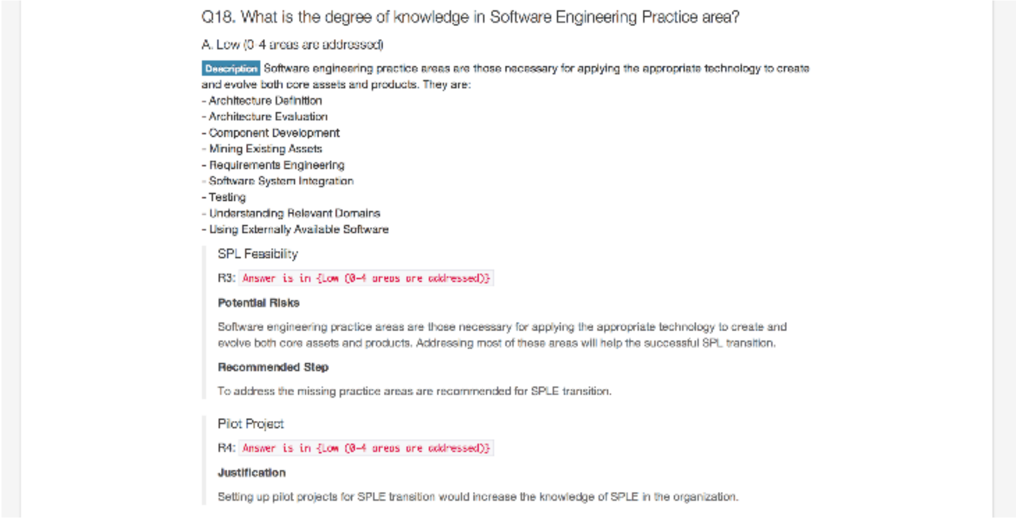


Figure 18. A View Demonstrating Questions to be answered

Figure 19 provides a sample view from the report. The report not only provides descriptions, but also conditions of rules that become true for the answer and related reasoning behind that rule. In this way, the user is able to observe the effects of their current condition for adopting SPLE through these explanations.


Q18. What is the degree of knowledge in Software Engineering Practice area?

A. Low (0-4 areas are addressed)

Description Software engineering practice areas are those necessary for applying the appropriate technology to create and evolve both core assets and products. They are:
- Architecture Definition
- Architecture Evaluation
- Component Development
- Mining Existing Assets
- Requirements Engineering
- Software System Integration
- Testing
- Understanding Relevant Domains
- Using Externally Available Software

SPL Feasibility

R3: Answer is in {Low (0-4 areas are addressed)}

Potential Risks

Software engineering practice areas are those necessary for applying the appropriate technology to create and evolve both core assets and products. Addressing most of these areas will help the successful SPL transition.

Recommended Step

To address the missing practice areas are recommended for SPLE transition.

Pilot Project

R4: Answer is in {Low (0-4 areas are addressed)}

Justification

Setting up pilot projects for SPLE transition would increase the knowledge of SPLE in the organization.

Figure 19. Generated report section for a question

In addition to the details of each question, the report provides the overall summary for the feasibility of SPLE and the selection of transition strategies. The feasibility of SPLE is represented using both radar charts and bar charts. Radar charts are used to display the SPLE feasibility with respect to different aspects. Bar charts are used to represent the evaluation of the transition strategies. Examples of these charts are shown in the subsequent sections.

Chapter 5

CASE STUDY DESIGN

In this chapter we describe the case study design for validating the defined objectives. For this we apply the guidelines described by Runeson and Höst [63]. We have followed the five steps: (1) case study design; (2) preparation for data collection; (3) execution with data collection on the studied case; (4) analysis of collected data; and, (5) reporting. The first two steps are discussed below. The last three steps will be discussed in Chapter 6.

5.1 Selected Case Studies

One of the important concepts in case study research is triangulation; which means to take different angles to consider the studied object. The main idea behind triangulation is that the results will be more trustable if different methods lead to the same result. To meet the criteria for triangulation we have adopted an overall case study design includes two different types of cases related to SPLE adoption. The first type of case is based on a retrospective analysis of case studies in the literature; the second case is based on a prospective case studies that discusses the qualitative analysis of CompanyX and CompanyY. We have applied *data triangulation* (multiple case studies), *observer triangulation* (multiple researchers/observers) and *methodological triangulation* (indirect data extraction from literature case studies and direct data extraction from industrial case) to increase the precision of the empirical research.

The two case studies from the literature have been selected from the list of companies in the Hall of Fame of the SPLC conference site. Among these we have selected Market Maker Software AG [64][10][65] and Salion, Inc. [66][67][68]. The reason for this choice was the availability of sufficient information published in papers and technical reports, to mine the answers for the questions that we have described in the previous section, and as such validly address the research questions.

Market Maker Software AG Software AG is a small company that provides products which track the values of the stock market and analyze them. The sources that we have used for Market Maker Software AG are [64][10][65]. Salion, Inc., Inc. is an enterprise software company dedicated to helping suppliers optimize their revenue acquisition process [66][67].

The case studies selected from the literature are based on document analysis. In addition to these, we have conducted case studies using direct data collection in CompanyX and CompanyY.

The first company is CompanyX, a software and systems company in the IT sector. The company operates in three main business areas: command and control (C2), simulation and training systems, and e-government systems. These areas are addressed by separate business divisions serving various customer segments. Earlier the company started to focus on software reuse and this resulted in a definition of application frameworks. To provide a broader support for reuse transitioning to a product line engineering approach is seriously considered. In the Information & Security technologies division, the management decided to analyze the transition to an SPLE approach, and related to this, the required transition strategy to mitigate risks wherever possible. The division aims to develop a set of products in the image processing domain.

The second company is CompanyY, a leading electronics and IT company in Turkey. The company mainly operates in communications and information technologies, defense systems, and microelectronics and radar systems. In the defense systems division, where they have successfully deployed other product lines in the past, on the horizon there is another SPL candidate. The management decided to benefit from the opportunity presented by the present study to evaluate their position in implementing that new SPL.

5.2 Case Study Design

The case study design fits the category of applied research and as such the primary purpose is to understand the impact of decision support on SPLE adoption within a real industrial context. Table 12 presents the case study design steps for the selected cases.

The particular goal for the retrospective case studies was to compare and assess the SPLE feasibility and strategy selection recommendation given by the DSS with the published results.

For the prospective case the primary goal was to assess the decision drift as well as the practicality of the DSS. Decision drift represents the difference between the decision on applying SPLE, before and after running *Transit-PL*. The concept is inspired from the notion of “scope drift” as proposed by Schmid and John [69] and can be considered synonymous. In our case we aim to capture the impact of *Transit-PL* on decision making in SPLE adoption, by asking a set of questions before and after running the tool.

Table 12. Comparison of Case Study Designs

Case Study Design Activity	**Retrospective Case Study(RCS)**		**Prospective Case Study(PCS)**	
Subject	Market Maker	Salion, Inc.	CompanyX	CompanyY
Goal	Comparing and assessing the SPLE feasibility and strategy selection recommendation given by the DSS with the published results		Assessing the decision drift Assessing the practicality of the DSS	
Research Questions	**RCS.RQ1:** To what extent is the decision on SPLE feasibility derived by the DSS in alignment with the decision of the case study? **RCS.RQ2:** To what extent is the decision on SPLE strategy selection derived by the DSS in alignment with the decision of the case study?		**PCS.RQ1:** To what extent does the DSS support the decision making of SPLE feasibility? **PCS.RQ2:** To what extent does the DSS support the decision making of the selection of transition strategy? **PCS.RQ3:** How practical is the DSS for the decision making on SPL adoption?	
Background and source	Official documents and papers		Official documents Project Managers	
Data Collection	Indirect data collection based on document analysis (the papers and technical reports)		Direct data collection through semi-structured interviews (mix of open and closed questions)	
Data Analysis	Qualitative Data Analysis using Radar Charts and Bar Charts		Qualitative Data Analysis using Radar Charts and Bar Charts	

The data collection and analysis techniques that were applied for the retrospective and prospective case studies were different. We describe these separately.

Data collection for the retrospective case studies was organized as follows:

1. In the first step we collected all the papers and technical reports related to the case study. This was carried out independently by two separate researchers. The selected studies were discussed and agreed. Since the number of papers is limited we did not encounter serious problems in this respect.
2. In the second step the answers to the questions as implemented in the DSS were mined from the papers. For this, each paper was thoroughly read and analyzed by the two independent researchers. For each mined answer the supporting evidence was explicitly recorded (e.g. “page X of Research paper Y”). The mined answers to the questions were kept in separate reports. Here, we had three different situations. First, the answer could be mined by the researcher because it was directly written in the knowledge source. Second, the answer of the question can be mined after interpretation of the researcher

using the contextual information in the knowledge source. Finally, the answer of the question could not be mined and the answer was left open by the researcher.

3. In the third step, the collected mined answers of the two independent researchers were compared and discussed to achieve the final set of answers. In case of a disagreement, the third researcher was advised to agree on the final answer.
4. The answers as derived in step 3 were used to feed the developed tool and the result for SPLE feasibility and the selected transition strategy.
5. In the final step the researchers analyzed the result of the tool for both the SPLE feasibility and the selected transition strategy. Hereby, also the provided motivation by the knowledge sources was analyzed and compared with the derived motivations using the DSS.

For the prospective case studies, data was directly collected during interviews with the decision-makers of both companies. In CompanyX, we conducted an interview with the engineering group manager of the division. He had around 15 years' experience in the IT business. The subject had a standard knowledge on large scale systematic software reuse and was aware of the SPLE concepts. However, he had not applied SPLE in the particular organization before. In CompanyY, we interviewed both the Software Group Manager of the division, and a team leader in the same division; both interviewees had over 15 years of experience in the IT business. Since the division had applied SPLE approach before, they possessed extensive experience in large scale systematic software reuse and were quite knowledgeable in SPLE.

In both cases, semi-structured interviews were conducted, in which a list of predefined set of questions were asked leading to open discussion (Appendix C). The interview was organized as follows:

1. First a meeting was scheduled with the decision-makers for the initial interview. The goal of this interview was to capture the initial thoughts and experience on SPLE adoption.
2. In the second step we gave a short presentation about the goal of the developed tool. We also briefly explained the operation of the tool, as well as the final outcome.
3. In the third step we let run the DSS tool by the decision-makers.
4. In the fourth step, the researchers analyzed the report that was provided by the tool after step 3.
5. In the fifth step, the researchers held a post interview with the subjects with the purpose of identifying the impact of the DSS on their decision making.
6. In the sixth step, the researchers collected data from the initial interview, report delivered by the tool, and the post interview. The assessment was carried out separately and later was discussed together to analyze the decision drift

Chapter 6

EVALUATION OF THE CASE STUDIES

In this chapter we report the results of the case study described in Chapter 5. In Section 6.1 we first discuss the results of the retrospective case studies, followed by Section 6.2 in which we discuss the results of the prospective case studies. In Section 6.3 we explicitly consider the threats to validity and our measures to mitigate them.

6.1 Retrospective Case Studies

The outcome of the execution of the case studies is threefold: (1) a radar chart representing the SPLE feasibility for the organization, (2) a table with the results for the selection of different transition strategies, and (3) a general evaluation and discussion regarding the case study. We separately discuss the results of Salion, Inc. and Market Maker Software AG.

The radar charts for assessing SPLE feasibility that resulted from the execution of the case study for Salion, Inc. is shown in Figure 20 through Figure 23. The charts show the results of the compiled answers of all the answers to the four BAPO dimensions separately. As stated before, the results show the answers that we could mine from the corresponding papers and do not reflect the interpretation of the researchers. From the radar charts we can derive the strengths and weaknesses about the feasibility of SPLE for Salion, Inc. First of all, considering the overall radar chart it appears that SPLE was largely feasible for Salion, Inc. because many answers to the questions seem to have a reply towards higher scores. The radar charts for each dimension highlight the answers from the dimension perspective.

The results for strategy selection are shown in Table 13. The first column of the table shows the ID of the question, and the second column shows the description of the question. The third column shows the answers to the question and the citations to the papers from which we mined the answers according to the protocol as defined in Section 5.2. The right columns of the table include the evaluation for the corresponding strategy with respect to the mined answer and the associated rule to the provided answer. The cells with the '+' sign (green) indicate that the extracted answer is positive for the corresponding SPLE strategy. The cells with the '-' sign (red) indicate a negative correlation, whereas the cells with the '0' sign denote a neutral correlation. For Salion, Inc., it appears that the tactical and pilot project strategies are compatible with each question, except for the ROI question. For the Big Bang strategy and the Incremental Strategy, some answers to the corresponding questions seem not to favor the selection of these strategies directly. Nevertheless, this does not mean that only the tactical and pilot strategies are feasible, because the company can focus on different business goals and as such put a higher weight on selected questions. In the real case of Salion, Inc., the important goal was to get higher revenue over a longer period of time. Hence, the incremental strategy was selected [66]. Table 13 shows the result for weighting each question equally. A dedicated weighting with respect to the companies goals can explain the final discussion around the feasibility and strategy selection decision.

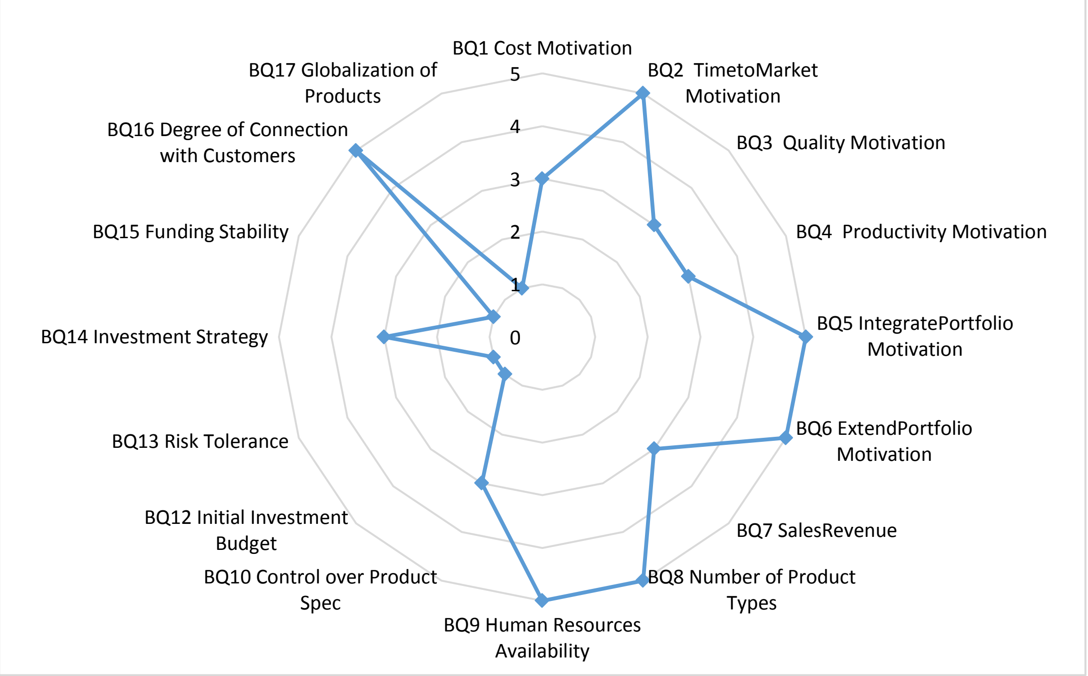


Figure 20. Radar Chart of SALION, INC. Feasibility (Business Dimension)

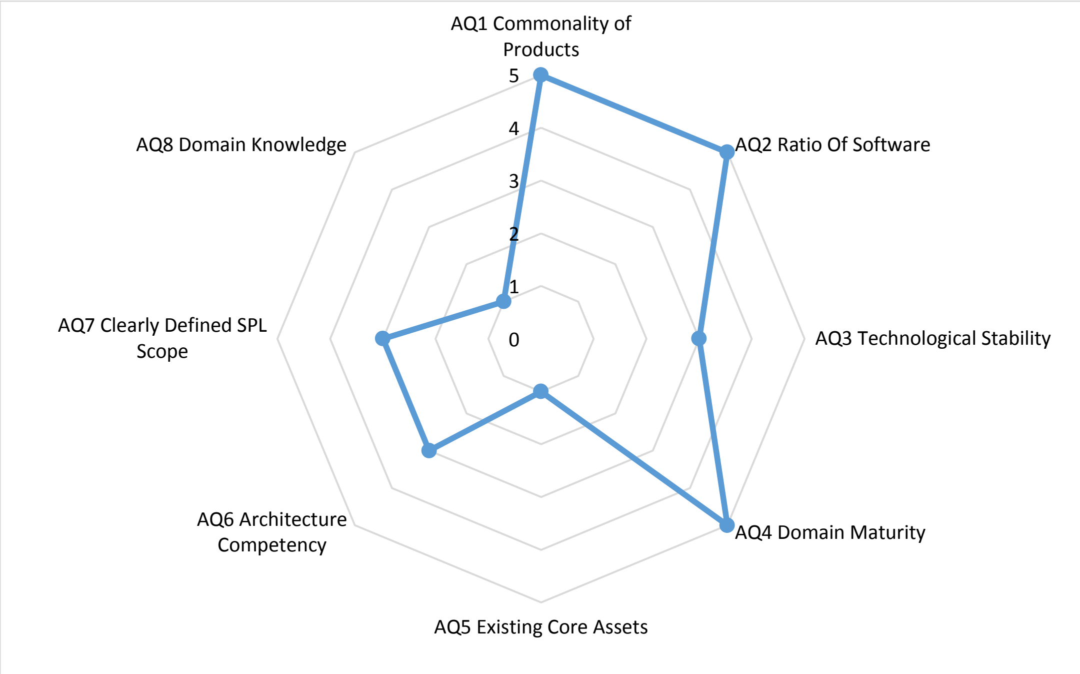


Figure 21. Radar Chart of SALION, INC. Feasibility (Architecture Dimension)

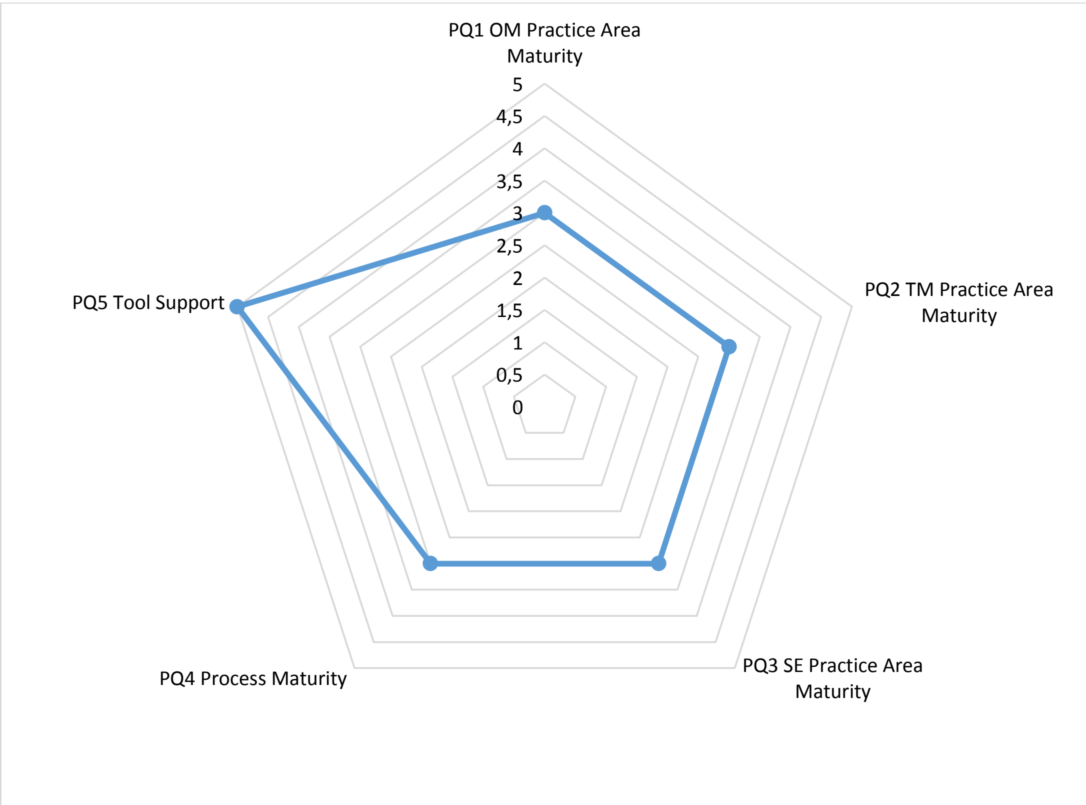


Figure 22. Radar Chart of SALION, INC. Feasibility (Process Dimension)

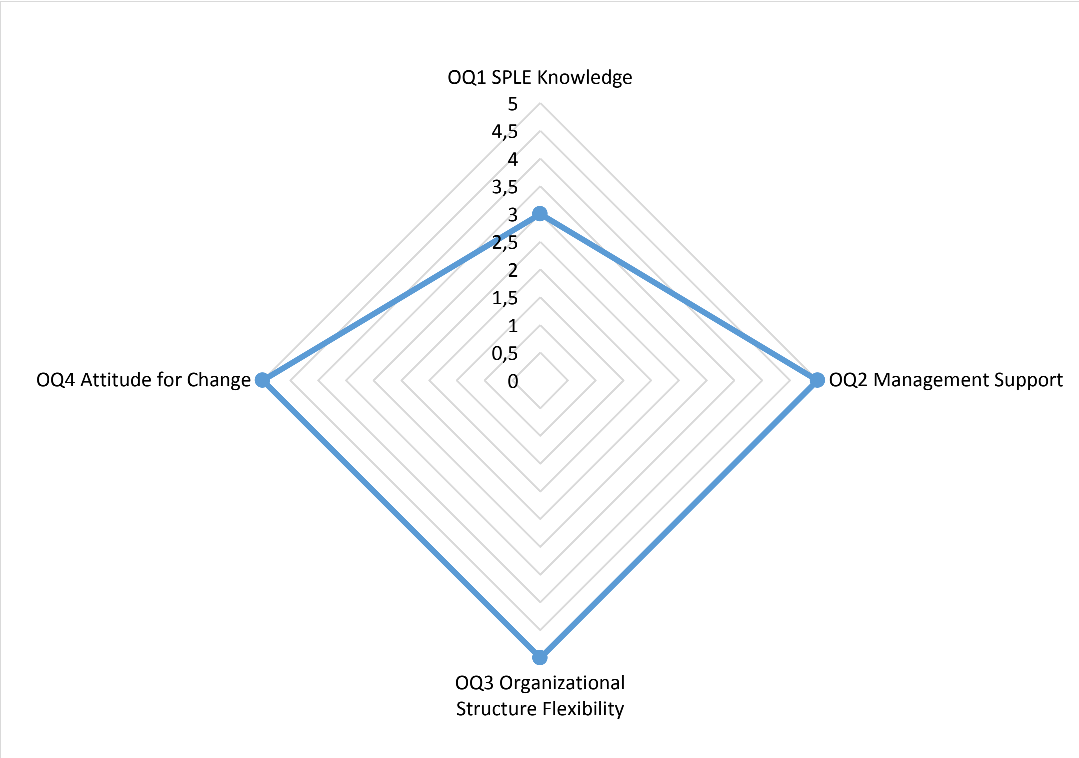


Figure 23. Radar Chart of SALION, INC. Feasibility (Organization Dimension)

The radar charts for Market Maker Software AG case study are shown in Figure 24 through Figure 27. The results for the strategy selection are shown in Table 14. Similar to the Salion, Inc. case study, a justification for the adoption of SPLE can be derived from the radar charts. Comparing to the Salion, Inc. case study, though, the Market Maker Software AG case study seemed to have more positive answers to the feasibility questions. In particular, the business perspective is very strong, but on the other hand, the questions regarding process perspective are lower, indicating the need to explore these weak points. For the Market Maker Software AG case study, the Big Bang strategy was selected as stated in the original publications. From Table 14 we can observe that all strategies were compatible. The reason why Big Bang was chosen could be based on the different weights of the questions. Comparing to Salion, Inc., the Big Bang strategy for the Market Maker Software AG seemed to be slightly more favorable.

Table 13. Salion, Inc. Strategy Recommendation[5]

QID	Question	Salion, Inc. Answer	Big Bang	Inc.	Tact.	Pilot
BQ9	Do you have human resources available for SPLE adoption?	Personnel is available but not all the time ([66] Section 3)	-	0	+	0
BQ10	To which extent can you control the product specification?	Medium ([67] Section 3.7)	0	0	+	+
BQ11	Do you intend to migrate legacy systems to your product line?	Strongly Disagree ([67] Section 3)	+	+	+	+
BQ12	What is the reserved budget for initial investment for transitioning to SPLE?	We do not plan to provide high investment initially ([68])	-	0	+	+
BQ13	To which extent can you cope with risks in case of failure?	Neutral (Average financial risks expecting to earn average returns) ([66] Section 5, [67] Section 5.1)	-	+	+	+
BQ14	When do you expect to get profit from the product line?	Medium term above average returns([68])	0	+	-	-
BQ15	How stable is the funding for the overall investment?	We will have problems with providing the overall investment ([66] Section 3)	-	-	+	+
AQ5	Will you make use of existing core assets in the SPLE?	Strongly Disagree ([67] Section 3)	-	0	+	+
AQ7	To what extent is the product line scope defined?	The product portfolio is largely known but not committed yet ([67] Section 3.1)	0	+	+	+
AQ8	What is the level of domain expertise in the application domain?	Low ([67] Abstract)	-	-	+	+
PQ4	What's the CMMI maturity level of the organization?	CMMI 3 ([67] Abstract)	+	+	+	+
OQ1	What's the level of SPLE knowledge in the organization?	Medium (We are aware of SPLE, but have never applied it) ([67] Section 2)	0	0	+	+

[5] Incremental Introduction Strategy (Inc.), Tactical Approach (Tact.), Pilot Project Strategy(Pilot).

QID	Question	Salion, Inc. Answer	Big Bang	Inc.	Tact.	Pilot
OQ2	Who is the highest level of sponsor for SPL transition?	CEO ([67] Section 5.1)	+	+	+	+
OQ3	To what extent can you afford to adapt the organization structure?	We can change the organization structure according to the needs for SPLE ([67] Section 3.10)	+	+	+	+
OQ4	What's the attitude for change in the organization?	Open to Change ([67] Section 5.2)	+	+	+	+

Figure 24. Radar Chart of Market Maker Software AG Feasibility (Business Dimension)

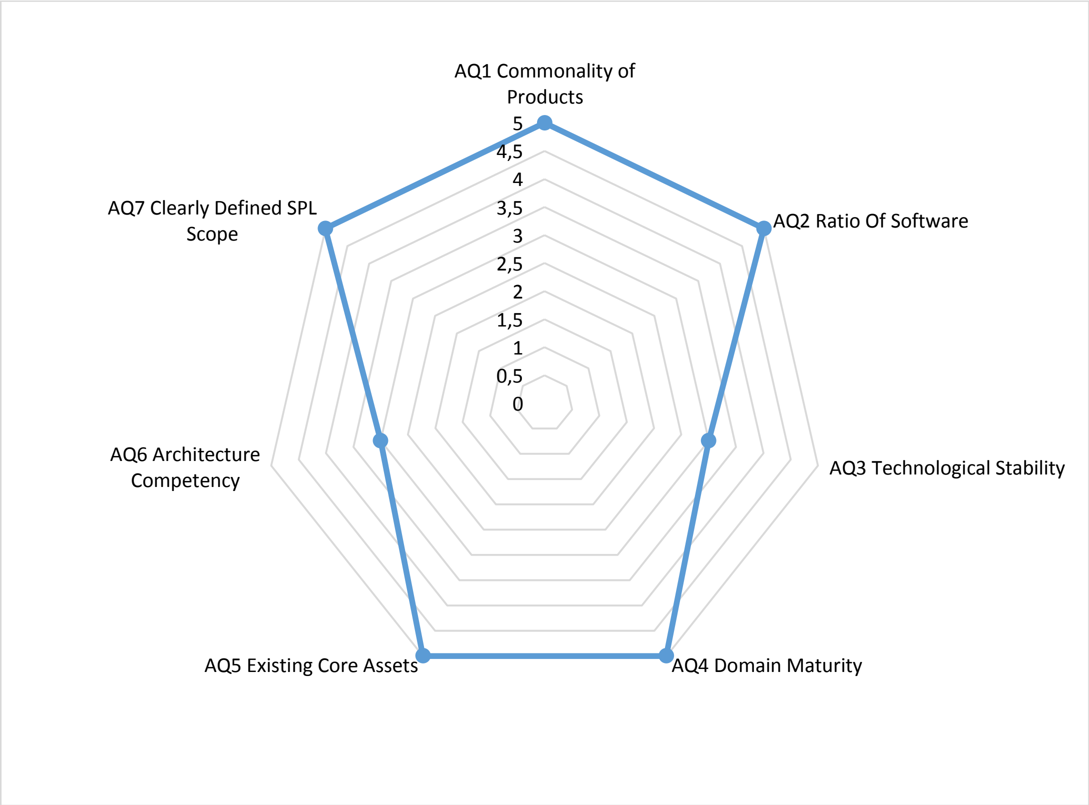


Figure 25. Radar Chart of Market Maker Software AG Feasibility (Architecture Dimension)

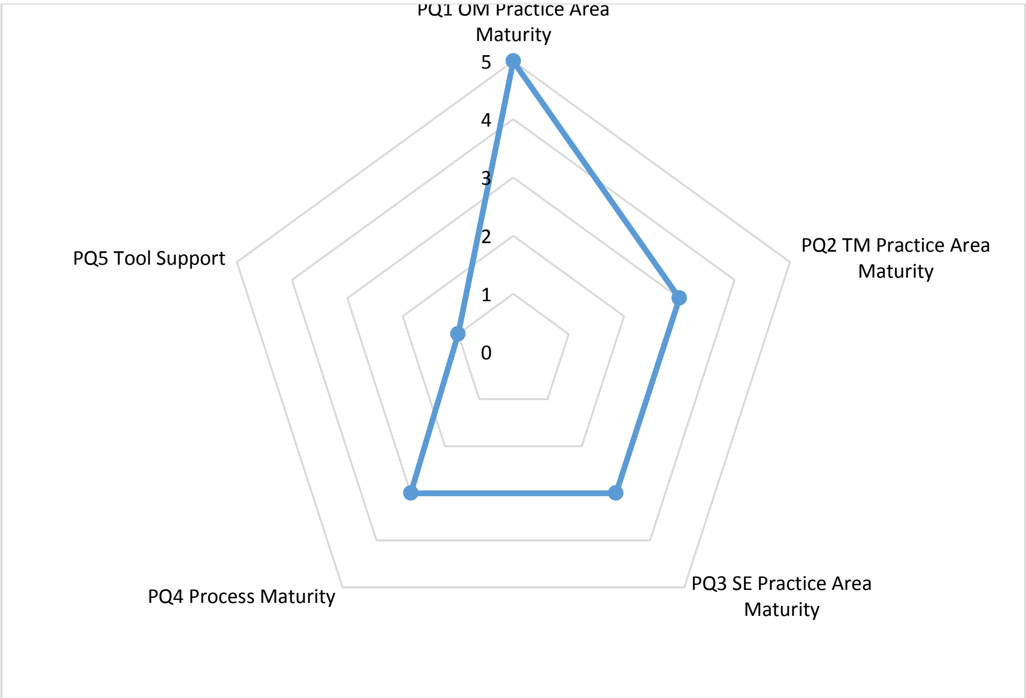


Figure 26. Radar Chart of Market Maker Software AG Feasibility (Process Dimension)

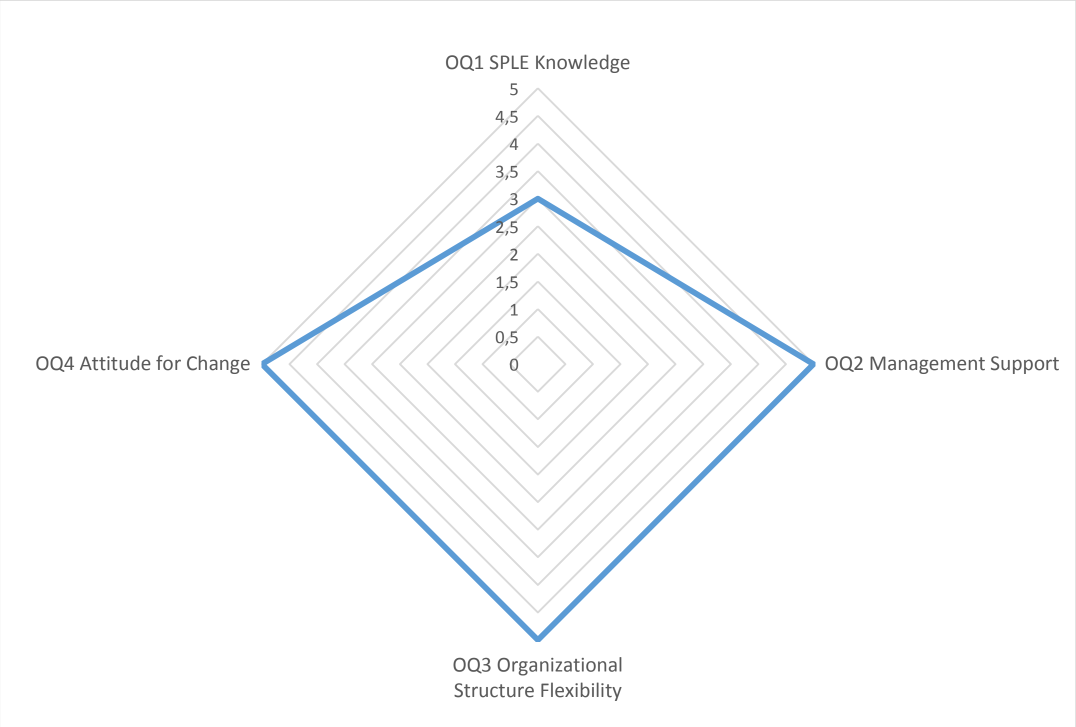


Figure 27. Radar Chart of Market Maker Software AG Feasibility (Organization Dimension)

Table 14. Market Maker Software AG Strategy Recommendation

QID	Question	Market Maker Answer	Big Bang	Inc.	Tact.	Pilot
BQ9	Do you have human resources available for SPLE adoption?	Yes, we do not have problems with allocating human resources ([65] Section 1)	+	+	+	+
BQ10	To what extent can you control the product specification?	High ([10] Section 11.4.1)	+	+	+	+
BQ11	Do you intend to migrate legacy systems to your product line?	Strongly Disagree ([65] Section 3)	+	+	+	+
BQ12	What is the reserved budget for initial investment for transitioning to SPLE?	We can totally afford the required upfront investment ([65] Section 1)	+	+	+	+
BQ13	To what extent can you cope with risks in case of failure?	Can moderately cope with risk ([65] Section 1)	-	+	+	+

QID	Question	Market Maker Answer	Big Bang	Inc.	Tact.	Pilot
BQ14	When do you expect to get profit from the product line?	Long term substantial returns ([65] Section 5.2)	+	0	-	-
BQ15	How stable is the funding for the overall investment?	Funding is not a problem ([65] Section 2)	+	+	+	+
AQ5	Will you make use of existing core assets in the SPLE?	Strongly Agree ([65] Section 1))	+	+	0	0
AQ7	To what extent is the product line scope defined?	We have a well-defined product portfolio and roadmap ([64] Section 5)	+	+	+	+
AQ8	What is the level of domain expertise in the application domain?	The company has a few years of experience and produced several products in the application domain (High) ([10] Section 11.2)	+	+	+	+
PQ4	What's the CMMI maturity level of the organization?	CMMI 3 ([64] Section 3)	+	+	+	+
OQ1	What's the level of SPLE knowledge in the organization?	Medium (We are aware of SPLE have never applied it) ([65] Section 1)	0	0	+	+
OQ2	Who is the highest level of sponsor for SPL transition?	CEO ([65] Section 2)	+	+	+	+
OQ3	To what extent can you afford to adapt the organization structure?	We can change the organization structure according to the needs for SPLE([64], [65])	+	+	+	+
OQ4	What's the attitude for change in the organization?	Open to Change ([64], [65])	+	+	+	+

RCS.RQ1: To what extent is the decision on SPLE feasibility derived by the DSS in alignment with the decision of the case study?

The analysis above shows that the SPLE feasibility results seem to be in alignment with the decision that was made in both the Salion, Inc. and Market Maker Software AG publications. Since both companies were in the Hall of Fame of SPLC and were evaluated by SPLE experts in the domain, we assume that SPLE was indeed feasible. The proposed DSS provides the same conclusion. The DSS not only shows that SPLE is feasible, but that it also helps to provide a clear rationale for the overall decision. In particular, it shows both points in favor and points against the selection of SPLE. For example; in the case study on Salion, Inc., we observe that domain knowledge was evaluated as low, which actually impedes the decision for SPLE adoption. The DSS indicated this as a risk, and provides recommendations for mitigating this risk. The original publications on Salion, Inc. indicate that they have successfully mitigated this risk through the hiring of domain experts. Similarly, for the Market Maker Software AG case study we can observe from the radar charts that the required product line tool support was missing and this was indicated as a risk, the corresponding recommendation being provided by the tool. In the Market Maker Software AG case study, despite this risk it was decided to go on with SPLE because of the significantly positive scores for the other questions.

RCS.RQ2: To what extent is the decision on SPLE strategy selection derived by the DSS in alignment with the decision of the case study?

The DSS is in alignment with respect to the decision on strategy selection. Using the DSS for each of the implemented strategies a clear overview regarding the compatibility of the strategies is given. For both case studies, we have observed that the rationale for the selected strategies can also be derived based on the reasoning in the DSS. In the Salion, Inc. case, a reactive, incremental strategy was selected, while in the Market Maker Software AG case the Big Bang strategy was preferred. Again the DSS provides the scores for the four different strategies as well as the underlying rationale. For example, for the Salion, Inc. case study the output of the DSS shows that for the incremental strategy selection, the funding for the overall investment and the domain expertise in the application domain were both low, constituting an indication against the incremental strategy. Here we can observe that domain knowledge which was evaluated as low has actually a negative impact on the incremental strategy. Salion, Inc. still decided to select the incremental strategy due to the other related benefits. As stated above, Salion, Inc. indicated that they have successfully mitigated this risk by hiring domain experts. In the Market Maker case, as also emphasized in reference texts, all the strong indicators for Big Bang strategy were present such as dedicated human resources for SPLE adoption, clear insight on the future of the market and current products because of well-defined product portfolio scoping. Although the Incremental strategy is also plausible because of the long term ROI preference of the organization, Big Bang strategy was used for SPLE adoption.

6.2 Prospective Case Studies

The overall outcome of the execution of the industrial case studies is as follows:

(1) Radar charts representing the SPLE feasibility for the organization (Figure 28 through Figure 31 for CompanyX, Figure 32 through Figure 35 for CompanyY)

(2) Tabulated results for the selection of different transition strategies (Table 15 for CompanyX, Table 16 for CompanyY)

(3) General evaluation and discussion regarding the case study

(4) Discussion and evaluation of the pre- and post-interview findings.

We separately discuss the results of CompanyX and CompanyY in the following subsections.

6.2.1 CompanyX

The case study was carried out in two phases. In the first phase, the tool was used by a small group within the company in order to garner feedback about it. The feedback was related to the overall setup, the ease of use, as well as the contents of the support provided. The feedback was related to the report format, the question set, the rules and the corresponding descriptions. The users reported the points that were less clear and that required further improvement. Based on the provided feedback the initial tool was further enhanced. This first phase took was completed within four weeks.

In the second phase, we started the actual evaluation for the company. During this phase, the tool was used by an Engineering Group Manager (EGM) who has an impact on the decision for adopting SPLE. The application of the tool took around three hours, including pre-interview, running of the tool and post-interview. Based on the answers of the EGM to the tool questions, the report was generated by *Transit-PL*. Later on the report was further enhanced with input from the pre- and post-interviews.

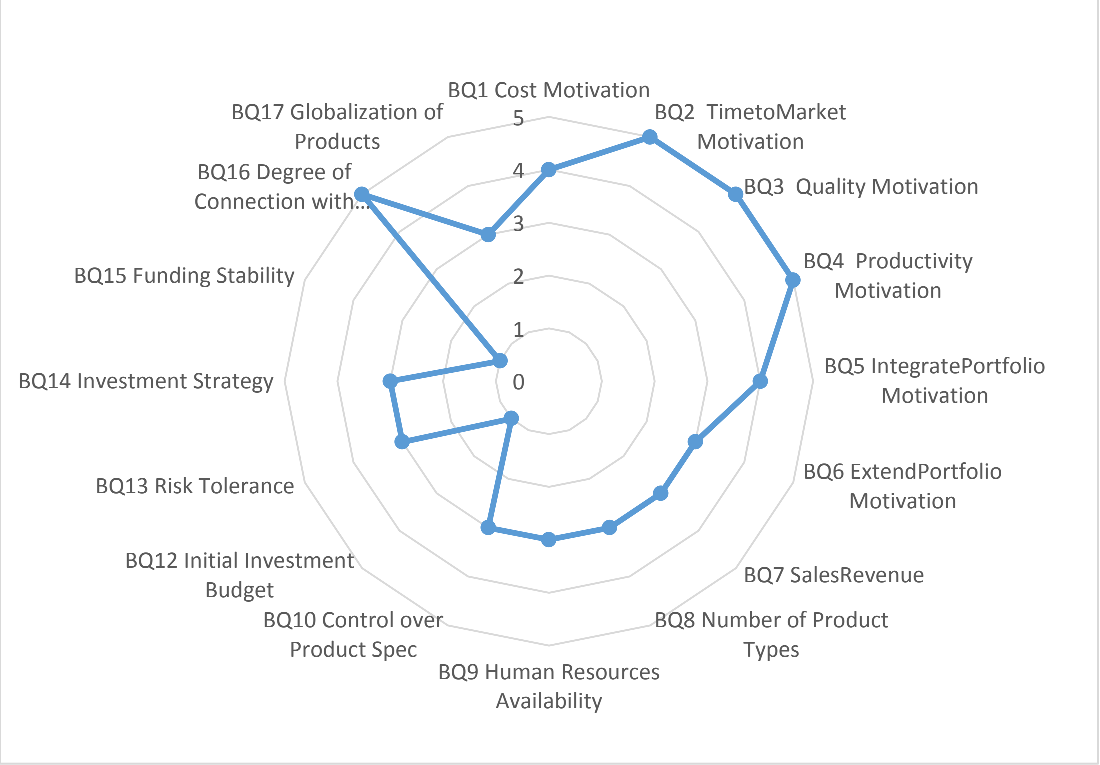


Figure 28. Radar Chart of CompanyX Feasibility (Business Dimension)

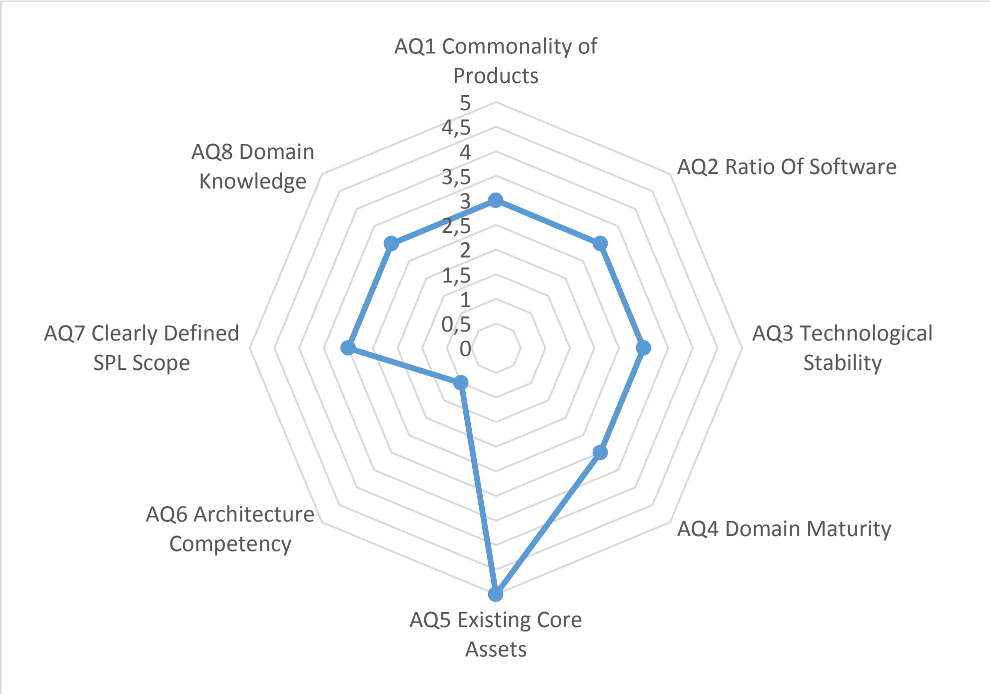


Figure 29. Radar Chart of CompanyX Feasibility (Architecture Dimension)

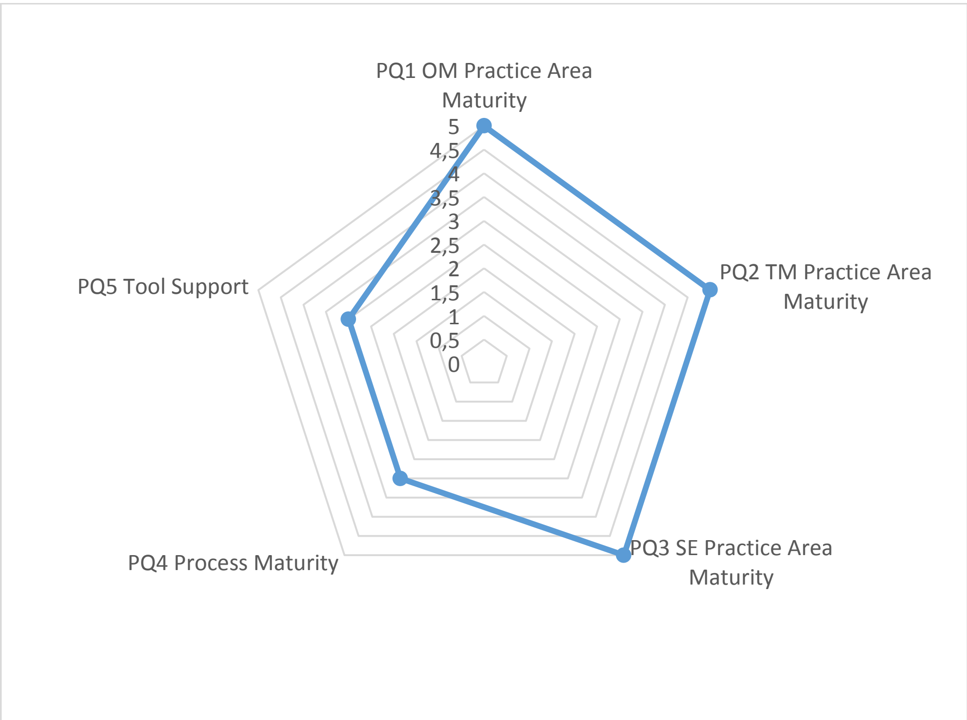


Figure 30. Radar Chart of CompanyX Feasibility (Process Dimension)

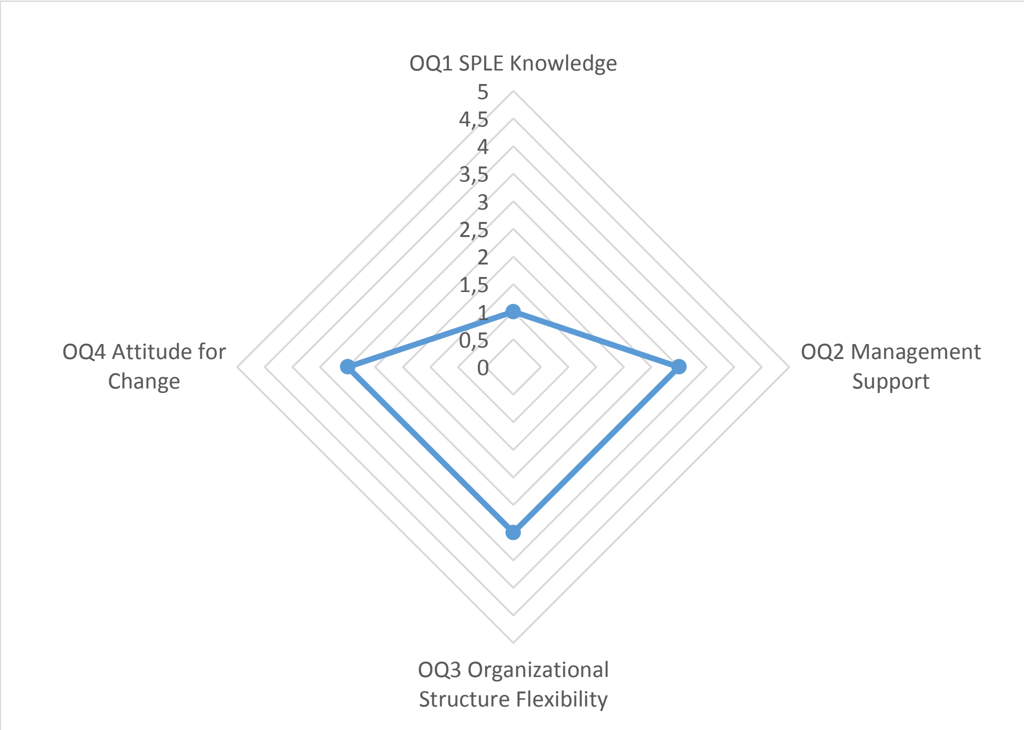


Figure 31. Radar Chart of CompanyX Feasibility (Organization Dimension)

Table 15. Strategy Recommendation in the Prospective Case Study (CompanyX)

QID	**Question**	**Company Answer**	**Big Bang**	**Incr.**	**Tact.**	**Pilot**
BQ9	Do you have human resources available for SPLE adoption?	Personnel is available, but not all the time	-	0	+	0
BQ10	To what extent can you control the product specification?	Medium	0	0	+	+
BQ11	Do you intend to migrate legacy systems to your product line?	Agree	-	+	+	+
BQ12	What is the budget reserved for initial investment for transitioning to SPLE?	We have no current plans for such investment	-	0	+	+
BQ13	To what extent can you cope with risks in case of failure?	Can moderately cope with risk	-	+	+	+

QID	Question	Company Answer	Big Bang	Incr.	Tact.	Pilot
BQ14	When do you expect to realize profit from the product line?	Medium term above average returns	0	+	-	-
BQ15	How stable is the funding for the overall investment?	We will have problems providing the overall investment	-	-	+	+
AQ3	What's the level of technological change (refresh rate) in the domain?	Medium	0	0	0	0
AQ5	Will you make use of existing core assets in the SPLE?	Strongly Agree	+	+	0	0
AQ7	To what extent is the product line scope defined?	The product portfolio is largely known but not yet committed	0	+	+	+
AQ8	What is the level of domain expertise in the application domain?	The company has limited experience and produced at least one product in the application domain	0	+	+	+
PQ4	What's the CMMI maturity level of the organization?	CMMI 3	+	+	+	+
OQ1	What's the level of SPLE knowledge in the organization?	Low (Do not know SPLE; never applied it)	-	-	+	+
OQ2	Who is the highest level of sponsor for SPL transition?	Lower-Level Management	-	-	+	+
OQ3	To what extent can you afford to adapt the organization structure?	The organization structure can be slightly changed to adopt SPLE	0	0	+	+
OQ4	What's the attitude for change within the organization?	Neutral	0	0	0	0

The radar charts for assessing SPLE feasibility that resulted from the execution of the case study for the organization is shown in Figure 31. The top-level charts show the results of the compiled answers of all the answers to the four BAPO dimensions. The lower charts show the scores to the answer of the separate dimensions. The results for strategy selection are shown in Table 15. From the radar charts we can derive the strengths and weaknesses regarding the feasibility of SPLE for the industrial case.

PCS.RQ1: To what extent does the DSS support the decision making of SPLE feasibility?

In the pre-interview, it appeared that the EGM was still hesitant about adopting SPLE because of the many unknown aspects and the risks. Several reasons were mentioned about the benefits of SPLE and the possible barriers, but there still wasn't full confidence in adopting SPLE would be indeed the right step.

After running the tool, the DSS seemed to have a direct impact on the opinion of the EGM. In the post-interview the EGM made the following important remarks:

"After using this tool, my ability to persuade upper management on SPLE adoption is now much stronger. I have more data and knowledge to persuade the upper management, which is important to launch the SPLE activities."

"I now see that there are also other barriers related to SPLE adoption which I was not aware of. The recommended steps given by the tool related to these barriers are really useful and help us to prepare for these in time."

"We have a better insight into the strengths and weaknesses with respect to SPLE. SPLE seems indeed more feasible now."

As can be observed from the statements of the EGM, there was a clear decision drift regarding SPLE adoption. The EGM indicated that besides the overall results, the explicit consideration of each aspect, and the explanation of the impact of each answer on the feasibility decision, made many things clearer. He stated that not only the benefits but also risks were clearer and this enabled him to prepare mitigation strategies. The EGM also stated that he was now more confident that adopting SPLE was the right decision for his company.

PCS.RQ2: To what extent does the DSS support the decision-making of the selection of transition strategy?

The EGM had some standard knowledge about transition strategies, but did not have in-depth knowledge on the relation of the aspects to the corresponding strategies. Before running *Transit-PL*, the EGM responded that he would more likely choose an Incremental approach but that this was actually because a Big Bang approach was not feasible at all. After the interview his response was either Incremental or Tactical, and he indicated that he had now a clear justification for the strategy selection. Again, since he became informed about the risks, he could prepare the proper planning of the transition using the selected strategy.

PCS.RQ3: How practical is the DSS for the decision-making on SPL adoption?

This was assessed via two questions in the post interview. First we asked the question "How practical was *Transit-PL*?" This question included a 5-point Likert scale (strongly disagree to strongly agree) for the answers. The EGM gave a 4, indicating that he was quite satisfied with the practicality of the tool. He added *"I won't have time to read all those papers and analyze the aspects related to strategy selection. This tool helps me a lot to identify the* *possible strategies and provide a justification for the selection. The tool is indeed very practical and useful".*

The second question "Will you use *Transit-PL* again?" was an open-ended question. Here the EGM answered that he will definitely use the tool again in the future for other candidate product lines. He also gave some recommendations for improvement: *"The recommended step descriptions in the tool are helpful, but some of them are obvious from the phrase of the questions".* He also added *"it would be helpful, if the recommended steps could include further references to other sources to obtain more information".*

In the 6 months after the case study was conducted in CompanyX, the following activities related to the SPLE adoption have been observed;

- Hiring new architects: In CompanyX one of the main drawbacks to SPLE feasibility was the lack of architecture competency within the organization. This point was also brought up by the Decision Support tool, recommending the organization to obtain further training in architecture, or hire expert architects. The organization has since hired an expert architect to address this issue.
- Tool Support: Although the organization has strong tool support for single system development, one of the points identified during the case study was the lack of tool support for SPLE. During the last 6 months, the organization started exploring alternatives for an application lifecycle management (ALM) tool suite that will address this issue.

These activities have confirmed the influence of the application of our decision support model.

6.2.2 CompanyY

The case study was carried out with the Software Group Manager (SGM) and a Team Leader who has an impact on the decision for adopting SPLE. The pre-interview questions were emailed before the interview to save time. The application of the tool took around 2.5 hours including pre-interview, running of the tool and post-interview. Based on the answers of the SGM to the tool questions, the report was generated by *Transit-PL*. Later on, the report was further enhanced with input from the pre- and post-interviews.

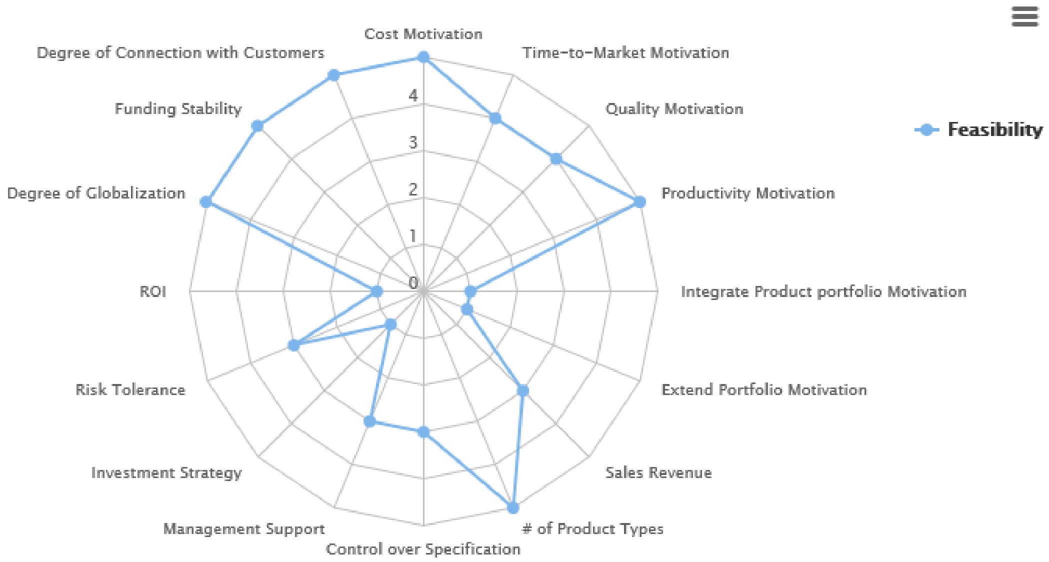


Figure 32. Radar Chart of CompanyY Feasibility (Business Dimension)

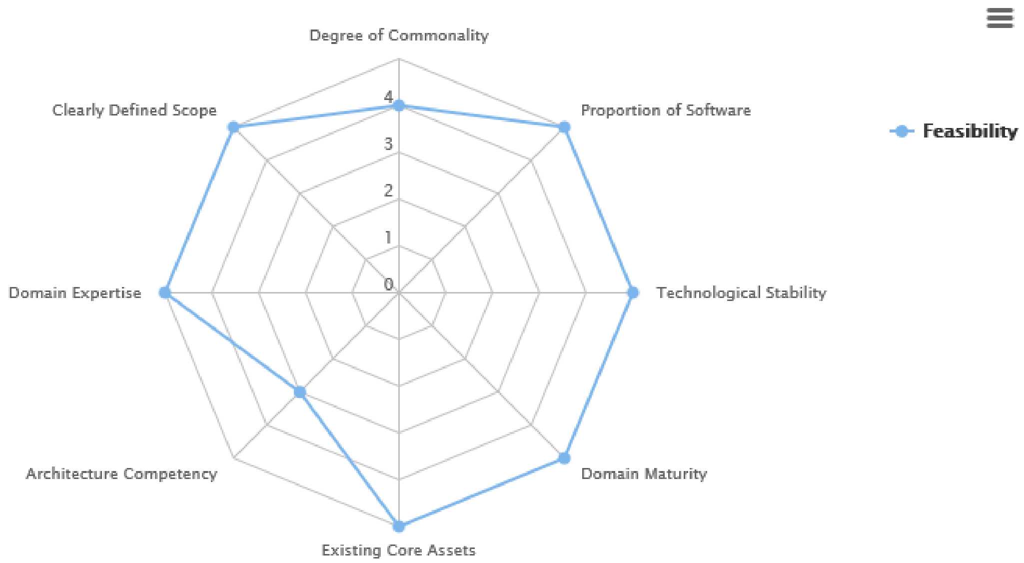


Figure 33. Radar Chart of CompanyY Feasibility (Architecture Dimension)

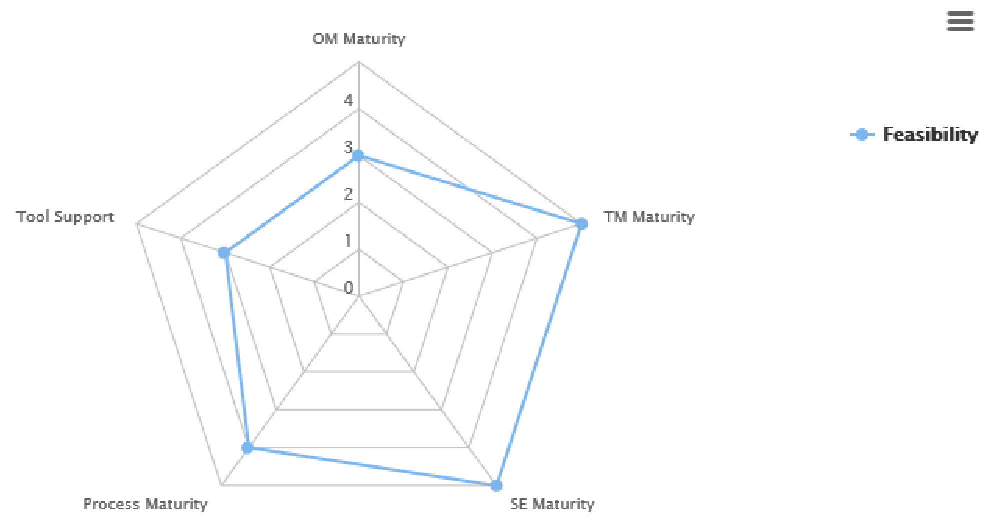


Figure 34. Radar Chart of CompanyY Feasibility (Process Dimension)

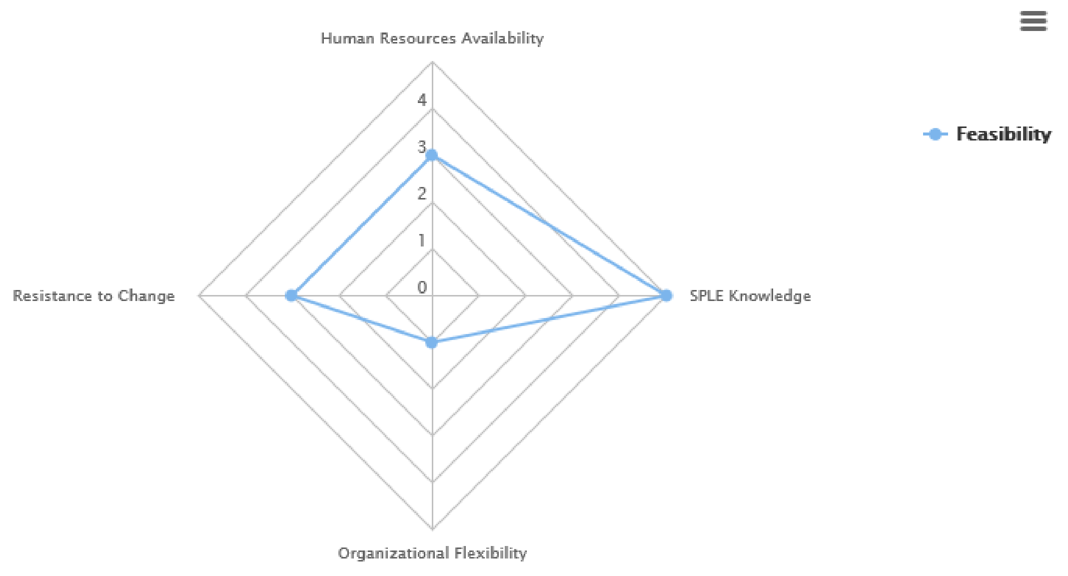


Figure 35. Radar Chart of CompanyY Feasibility (Organization Dimension)

The radar charts for assessing SPLE feasibility that resulted from the execution of the case study for the organization are shown in Figure 32 through Figure 35. It appears that SPLE was largely feasible for the company because most of the questions seem to have a reply towards higher scores. According to the radar charts, there are only a few risky areas such as Investment Strategy and Organizational Flexibility. This means that transitioning to SPLE will be favorable, but should be carried out cautiously. The report indicates the risks and the recommendations to mitigate them.

Table 16. Strategy Recommendation in the Prospective Case Study (CompanyY)

QID	Question	Company Answer	Big Bang	Incr.	Tact.	Pilot
Q18	Do you have human resources available for SPLE adoption?	Personnel is available, but not all the time	-	0	+	0
Q19	To what extent can you control the product specification?	Medium	0	0	+	+
Q20	What's the level of SPLE knowledge in the organization?	High (We know SPLE; previously applied)	+	+	+	+
Q21	Do you intend to migrate legacy systems to your product line?	Strongly Disagree	-	+	+	+
Q27	Will you make use of existing core assets in the SPLE?	Strongly Agree	+	+	0	0
Q29	When do you expect to realize profit from the product line?	Incremental return in the short-term	-	+	+	+
Q30	To what extent can you afford to adapt the organization structure?	The organization structure is fixed, we need to adopt the SPLE process with the given organization structure	-	-	+	+
Q31	What's the CMMI maturity level of the organization?	High (e.g. CMMI 4)	+	+	+	+
Q32	What's the attitude for change within the organization?	Neutral	0	0	0	0
Q34	What is the level of domain expertise in the application domain?	The company has a few years of experience and produced several products in the application domain (High)	+	+	+	+
Q37	To what extent is the product line scope defined?	We have a well-defined product portfolio and roadmap	+	+	+	+
Q38	How stable is the funding for the overall investment?	Funding is not a problem	+	+	+	+

As shown in Table 16 for the strategy selection, adopting a Big-bang strategy does not seem feasible. The tool recommends a tactical approach closely followed by incremental and pilot approaches. Similar to the case for feasibility, the tool provided a detailed explanation about the motivation for these scores. The final overall report is around 15 pages long, including the radar charts, the tables and the detailed explanations.

PCS.RQ1: To what extent does the DSS support the decision-making of SPLE feasibility?

Because the organizations had several successful SPLE experiences in the past, the SGM was confident that SPLE would be feasible, however as he indicated in the pre-interview, his only reservation was to persuade the system engineering team which was a stakeholder in the adoption as well. He said he would be more likely to persuade the system engineering team with the results that *Transit-PL* provided. He also noted that the weakness in organizational practice area that was indicated in the outcomes.

In CompanyY case, there was a smaller decision drift regarding SPLE adoption feasibility compare to CompanyX case. The SGM indicated that their previous experience on SPLE influence the benefit and usability of *Transit-PL*. He further added that although their decision drift was minimal, he confirmed that the questions are adequate for assessing the feasibility of SPLE adoption.

PCS.RQ2: To what extent does the DSS support the decision-making of the selection of transition strategy?

In this case it appeared that the decision for the selection of the transition strategy did not really change after applying *Transit-PL*. The SGM already had extensive knowledge about transition strategies and they had successfully applied the incremental approach in their previous projects. As such, before the interview the SGM indicated that they prefer the incremental approach and he gave plausible reasons for this as also stated in the literature. After the interview, the opinion about the selection of the transition strategy did not change, but the SGM indicated that the tactical approach was actually also interesting and they would investigate this in detail. In short, we could identify a smaller decision drift compared to CompanyX. But in this case, the tool helped to confirm and evaluate the opinions on the selection of transition strategies. Furthermore, the automatically provided risks and recommendations were considered useful from the business case preparation and documentation perspective.

PCS.RQ3: How practical is the DSS for the decision-making on SPL adoption?

This was assessed via two questions in the post interview. First we asked the question "How practical was *Transit-PL*?" This question included a 5-point Likert scale (strongly disagree to strongly agree) for the answers. The SGM gave a 4, indicated that he was quite satisfied with the practicality of the tool.

The second question “Will you use *Transit-PL* again?” was an open-ended question. Here the SGM answered that he will consider using the tool again in the future for other candidate product lines. He also gave question recommendations that will assess the architecture competency in detail.

6.3 Threats to Validity of Case Studies

Below we describe the potential threats to validity of the described four case studies and briefly discuss the mitigation strategy for each threat.

Construct validity refers to what extent the operational measures that are studied really represent what the researcher had in mind, and what was investigated according to the research questions [70]. Table 17 shows the various identified threats to construct validity, together with their counter measures.

Internal Validity relates to a causal relationship between a treatment and the outcome. This threat seems to be different for the retrospective case studies and the industrial case study. For both cases, the outcome is the decision on SPLE feasibility and the strategy selection. However, the applied treatment is different. In the case of the retrospective case studies, we relied on publications of case studies that we could find, so there could be information missing from these cases that could affect the outcome. To mitigate this threat we have picked literature case studies from the Hall of Fame where we found a lot of information in published papers. In the industry case, we relied on the answers of the interviewee from the organization. In the prospective case, other unforeseen organization specific variables could have had an impact on the derived decisions. To mitigate this threat, we asked open-ended questions in the interviews after the tool application in order to expose any missing information.

External Validity concerns the ability to generalize the results of the study. Literature-based retrospective cases provide an assessment of the long term validity of DSM outcomes, whereas the actual industrial case study provides an assessment of the decision drift caused by the application of the DSS tool. Hence the multiple case study design has provided grounds for assessment of the effectiveness of the proposed DSM. One limitation of the study is that we were only able to run DSM against positive cases (where SPLE feasibility was positive). The reason for that is: researchers are more likely to publish positive results, rather than publishing studies that have negative results. In our review, we observed that many papers are also written by industry professionals reporting on their experiences in SPLE. It is generally known that companies do not readily publish negative results and likewise, publication bias might be a real concern here. As a result, we could only validate our DSM against positive case studies. In this study, we have applied *Transit-PL* to Salion, Inc. and Market Maker as retrospective case studies. Similarly, we believe that we could use *Transit-PL* for any other published case studies on SPLE adoption.

Table 17. Threats to construct validity and counter measures applied in case studies

Threat	Countermeasure
Inappropriate mining of answers from the retrospective case studies.	Detailed data extraction protocol explained in Section 5.2
In appropriate mining of decisions by researchers regarding SPLE feasibility and strategy selection in the corresponding retrospective case study papers.	
Wrong interpretation of the descriptions of the tool questions by the interviewed persons in the prospective case studies.	To ensure uniqueness of interpretations of the questions, for each question, we have added a detailed description of the concepts being asked in that question. We have applied the principles described in Kitchenham and Pfleeger [71] in constructing the questions and answers. That was from feedback we gathered during several pilot runs in the organization.
Wrong interpretation of the description of the answers by the interviewed persons, and likewise the wrong selection of answers in the prospective case studies.	This is especially important for the Likert-scale types of questions. In most of the cases, it is difficult to differentiate for example between a "Strongly Agree" and "Agree". This was also one of the comments from the trial runs. To mitigate this per each Likert-scale question, we have tried to define each scale as much as possible to avoid confusion. We made several pilot runs to ensure the questions and answer choices were clear and understandable. Our pilot study group includes team leaders, experienced engineers, and project managers.
Wrong interpretation of the open questions by the interviewed persons in the prospective case studies.	To mitigate this threat we have verified the interpretation of the questions with interviewees.
Wrong interpretation by the researchers of the answers provided by the interviewees in the prospective case studies.	To mitigate this threat two of the researchers were present in the interview to achieve observer triangulation.

Chapter 7

CONCLUSION

7.1 Summary

We have considered the decision for adopting SPLE, and the decision for the selection of the product line adoption strategy. Both decisions are important and critical for organizations who aim to adopt SPLE. Clearly, the decision for adopting SPLE and the selection of the strategy is not an all or nothing decision. This was one of the main reasons why we carefully identified and addressed the different aspects for SPLE adoption. For this we have provided a comprehensive SLR on SPLE adoption from which we identified 25 aspects that were derived from 31 primary studies. Based on the data extraction, we were able to construct 39 questions and 312 rules. The aspects, questions and rules by themselves are valuable in supporting the decision-making process.

To automate the process we have developed the DSS tool, *Transit-PL*, embodies these elements and provides a practical and complementary support for the decision-making process in an organization. The DSS that we have provided includes a large set of questions and rules which can be further enhanced when further knowledge is generated with the SPLE community. We have concluded from experience in its use by various professionals that the tool is of benefit to both practitioners and researchers. In our future work we will apply *Transit-PL* within different companies to support the transition process. In addition, since *Transit-PL* is freely available, use we also expect to collect feedback from users to further enhance the tool.

To provide a valid and objective evaluation, we carried out our empirical analysis by adopting a multiple case study approach, in which we used two case studies from the literature, and two case studies from industry that planned to apply SPLE. The two case studies from the literature were selected from the Hall of Fame of the SPLE conferences, and as such provide a reliable case for supporting retrospective analysis. With *Transit-PL* we could derive the similar decisions as described in the publications of the corresponding case study. Hence we can state that provided DSS is reliable, with the accumulated knowledge from the SLR, it can be used to support and derive the decision making on SPLE adoption. We have selected and described two case studies from the literature and we could easily conduct additional case studies as well. An important requirement here is of course that the publications regarding the case study should be existent and the required knowledge can be extracted in the retrospective analysis.

The prospective case studies also showed the practical benefits of the application of DSS to the decision-making process. Overall, we received very positive feedback from the decision-makers regarding both the tool and the presented questions and decisions. From the cases that we described, we could derive a clear decision drift after applying the DSS. An important issue here is that the decision making is made explicit and the decision-makers were supported by mature knowledge to provide an explicit rationale for their decisions.

Based on the results of the multiple case study validation, we can conclude that the constructed DSS has a clear supporting role in the decision-making process and as such will help to guide and justify the decisions regarding the SPLE and the strategy selection.

7.2 Major Contributions and Responses To Research Questions

- *RQ1: How can the SPLE feasibility of an organization with particular characteristics be assessed?*

  An extensive SLR that was presented in Chapter 3 has been conducted to answer this question. We were able to identify five existing SPLE feasibility approaches that we have discussed in Section 3.2.1. Based on the SLR, we identified 25 aspects that were derived from 31 primary studies. These aspects were presented in Table 3 through Table 6. Using these 25 aspects, we were able to derive 33 questions for assessing the SPLE Feasibility. The questions and rules have been formulated in the form of a DSM and implemented in *Transit-PL.*

- *RQ2: How can an appropriate transition strategy for an organization with particular characteristics be selected?*

  An extensive SLR that was presented in Chapter 3 has been conducted to answer this question. We were able to identify 6 different SPLE transition strategy classification that we have discussed in Section 3.2.2. Based on the SLR, we identified 25 aspects that were derived from 31 primary studies. These aspects were presented in Table 3 through Table 6. Using these 25 aspects, we were able to derive 21 questions for the decision of the selection of the product line adoption strategy. The questions and rules have been formulated in the form of a DSM and implemented in *Transit-PL.*

The proposed DSM and accompanying DSS, *Transit-PL* proposes a common skeleton for implementation of decision support process for adopting SPLE. The tool provides a decision support framework based on questions, rules and strategies with report generation capabilities to guide the transition process. The organizations that are planning to adopt SPLE can benefit from *Transit-PL* in the following ways:

- An initial contact point for practitioners before SPLE transition process;
- Creation of decision plans and collaboration of different ideas via these plans;
- Validation of plans by sharing with others and obtaining feedback;

- A detailed report on feasibility of SPLE and applicability of transition strategies based on given answers;
- Ability to (re)use and (re)design the predefined set of rules that are extracted from literature.

7.3 Limitations

Threats to validity and limitations of the study have been addressed in Section 3.3 and Section 6.3, where we have discussed the threats to validity of the SLR and the conducted case studies.

In summary the following limitations were observed related to the DSM:

- We were only able to run DSM against positive cases (where SPLE feasibility is always positive). It is known that researchers are more likely to publish positive results and refrain from publishing studies that have negative results. For retrospective cases, it is unlikely to find a negative case. For a negative outcome case (where SPLE feasibility is negative), we need to run more industrial case studies in the future.

- A total of four case studies were conducted to assess the validity of the proposed DSM. Two of the case studies were retrospective, and two of them were prospective case studies. Both of the prospective case studies were conducted in defense industry companies. Prospective case study validation was limited to a single domain. In the future, non-defense industry case studies would be necessary to establish the validity of the approach in other industries.

- For the prospective case studies, the interviews were conducted with the Engineering Group Manager for Company X and Software Group Manager and Software Team Leader for Company Y. If the interviews had been conducted with more people, we would possibly have been able to obtain a more precise picture of the respective organizations.

- When we compared the decision drift in CompanyX and CompanyY, we observed that in CompanyY, there was a smaller decision drift. As we have discovered in the interviews with both companies, *Transit-PL* seems to have lower impact in companies that have significant prior experience in SPLE.

7.4 Future Work

The DSM has been validated in two prospective case studies where we have collected usability feedback from industry. Currently *Transit-PL* has been used in case study assignment for SM 525 Software Product Line Management class at METU. With this method, we are planning to gather further feedback about both the usability of the tool, and the quality of questions and rules.

In the near future, *Transit-PL* will be used in various industries to support the decision-making process for SPLE adoption. We are planning to do five more prospective case studies in organizations operating in different domains, such as finance, e-government, consumer electronics etc. These multiple case study data could be used to identify trends, and various success and failure factors for SPLE adoption.

Another interesting approach would be to explore this DSM for System Product Lines, instead of only focusing on Software Product lines. Unfortunately, conventional product line engineering approaches have primarily focused on software product line engineering and no explicit support has been provided to support the integration of software with the hardware. It is worthwhile to extend the DSM to support System Product Lines as well. For this purpose, we are planning to diversify and increase the number of questions.

DSM that was presented in this dissertation explicitly focuses on decision making in the SPLE adoption process. Organizations that are adopting SPLE, also need transition support during the operation of SPLE. The DSM could be extended to include the operation phase. The inputs for the operation phase of SPLE should be gathered from the metrics. Some of these initial metrics are defined in our earlier work [14].

In the software reuse literature, recently software ecosystems have been attracting attention [72][73]. We have seen the trend of software product line companies increasingly adopting inter-organizational sharing of software platforms, in effect transitioning to software ecosystem platforms [74] [75][76]. In theory, the DSM that has been proposed in this thesis could be extended to include a Decision Support Model for transitioning to Software Ecosystems as well. Although some of the questions that were used in SPLE Adoption could be reused for Software Ecosystems, SLR for Software Ecosystems is needed to mine for questions, rules and suggestions.

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Appendix A – Identified Primary Studies for SLR

Id	Primary Studies
1.	Fritsch, C. and Hahn, R. 2004. Product line potential analysis. Software Product Lines. (2004), 95–97.
2.	Ahmed, F. and Capretz, L. 2006. Maturity assessment framework for business dimension of software product family. Journal of Interpretability in Business. 1, 1 (2006), 9–32.
3.	Ahmed, F. and Capretz, L.F. 2009. An organizational maturity model of software product line engineering. Software Quality Journal. 18, 2 (Oct. 2009), 195–225.
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5.	Bosch, J. 2002. Maturity and evolution in software product lines: Approaches, artefacts and organization. Software Product Lines. (2002), 257–271.
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7.	Buehne, S. et al. 2004. Exploring the context of product line adoption. 5th International Workshop on Software Product-Family Engineering. (2004), 19–31.
8.	Catal, C. 2009. Barriers to the adoption of software product line engineering. ACM SIGSOFT Software Engineering Notes. 34, 6 (Dec. 2009), 1.
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12.	Kircher, M. et al. 2006. Transitioning to a Software Product Family Approach - Challenges and Best Practices. 10th International Software Product Line Conference (SPLC'06) (2006), 163–171.
13.	Kuvaja, P. et al. 2011. Software Product Line Adoption–Guidelines from a Case Study. Software Engineering Techniques. 4980, (2011), 143–157.
14.	Van Der Linden, F. et al. 2004. Software Product Family Evaluation. Software Product Lines. 3154/2004, (2004), 110–129.
15.	McGregor, J.D. et al. 2002. Initiating software product lines. IEEE Software. 19, 4 (Jul. 2002),

Id	Primary Studies
	24–27.
16.	Niemelä, E. 2005. Strategies of product family architecture development. SPLC'05 Proceedings of the 9th international conference on Software Product Lines (2005), 186–197.
17.	Northrop, L.M. 2002. SEI's software product line tenets. IEEE Software. 19, 4 (2002), 32–40.
18.	Northrop, L. 2004. Software Product Line Adoption Roadmap. September (2004).
19.	Person, C. et al. 2009. State-of-the-art Survey for Product Lines. (2009).
20.	Pohl, K. et al. 2005. Software product line engineering: foundations, principles, and techniques. Springer.
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22.	Schmid, K. 2001. An assessment approach to analyzing benefits and risks of product lines. 25th Annual International Computer Software and Applications Conference. COMPSAC 2001 (2001).
23.	Schmid, K. and Verlage, M. 2002. The Economic Impact of Product Line Adoption and Evolution. IEEE software. 19, 4 (2002), 50–57.
24.	Schütz, D. 2010. Transition to Product Line Engineering. (2010).
25.	Simon, D. and Eisenbarth, T. 2002. Evolutionary introduction of software product lines. Software Product Lines. (2002), 272–283.
26.	Tekinerdogan, B. et al. 2010. Multidimensional classification approach for defining product line engineering transition strategies. Software Product Lines: Going Beyond (2010), 461–465.
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Appendix B – Identified Questions in the DSM

Q. ID	Question	Possible Answers
Q1.	What's the name of the organization?	N/A
Q2.	What's your name?	N/A
Q3.	What's your role in the organization?	N/A
Q4.	What's the organization size?	1-49 employees (small) 50-249 employees (medium) Over 250 employees (large)
Q5.	What's the application domain?	Mobile applications C2/C4ISR Medical/ healthcare Automotive industry Enterprise applications Electronics Other
Q6.	Is your motivation for adopting SPLE to reduce cost?	Strongly Agree – Agree – Neutral – Disagree – Strongly disagree
Q7.	Is your motivation for adopting SPLE to reduce time-to-market?	Strongly Agree – Agree – Neutral – Disagree – Strongly disagree
Q8.	Is your motivation for adopting SPLE to improve the product quality level?	Strongly Agree – Agree – Neutral – Disagree – Strongly disagree
Q9.	Is your motivation for adopting SPLE to increase productivity and become more efficient?	Strongly Agree – Agree – Neutral – Disagree – Strongly disagree
Q10.	Is your motivation for adopting SPLE to integrate the product portfolio?	Strongly Agree – Agree – Neutral – Disagree – Strongly disagree
Q11.	Is your motivation for adopting SPLE to extend the product portfolio?	Strongly Agree – Agree – Neutral – Disagree – Strongly disagree
Q12.	What is the expected sales revenue from your product portfolio?	High – Medium – Low
Q13.	What is the degree of commonality in the product portfolio?	81-100% 61-80% 41-60% 21-40% 0-20%
Q14.	What is the planned number of product types in the product portfolio?	High (>=5 products) Medium (3-4 products) Low (1-2 products)
Q15.	What's the proportion of software in a typical product?	81-100% 61-80% 41-60% 21-40% 0-20%

Appendix B – Identified Questions in the DSM (Continued)

Q. ID	Question	Possible Answers
Q16.	What's the level of technological change (refresh rate) in the domain?	High (refresh rate < 1 year) Medium (refresh rate 1 to 3 years) Low(refresh Rate > 5 years)
Q17.	What's the maturity of application domain?	High (stable; easy to forecast near future) Medium Low (relatively new; difficult to forecast near future)
Q18.	Do you have human resources available for SPLE adoption?	Yes, no problems allocating human resources Personnel is available, but not all the time We lack personnel
Q19.	To what extent can you control the product specification?	High – Medium – Low
Q20.	What's the level of SPLE knowledge in the organization?	High (We know SPLE; previously applied) Medium (Aware of SPLE; never applied it) Low (Do not know SPLE; never applied it)
Q21.	Do you intend to migrate legacy systems to your product line?	Strongly Agree – Agree – Neutral – Disagree – Strongly disagree
Q22.	What's the degree of knowledge in Organizational Management practice area?	High (>7 areas addressed) Medium (5-7 areas addressed) Low (0-4 areas addressed)
Q23.	What's the degree of knowledge in Technical Management Practice area?	High (>7 areas addressed) Medium (5-7 areas addressed) Low (0-4 areas addressed)
Q24.	What's the degree of knowledge in Software Engineering Practice area?	High (>7 areas addressed) Medium (5-7 areas addressed) Low (0-4 areas addressed)
Q25.	Who is the highest level of sponsor for SPL transition?	CEO Divisional Manager Engineering Manager Architects, Tech Leads None
Q26.	What is the budget reserved for initial investment for transitioning to SPLE?	We can completely afford the required upfront investment. We can mostly afford the required upfront investment. We have no current plans for such investment.

Appendix B – Identified Questions in the DSM (Continued)

Q. ID	Question	Possible Answers
Q27.	Will you make use of existing core assets in the SPLE?	Strongly Agree – Agree – Neutral – Disagree - Strongly disagree
Q28.	To what extent can you cope with risks in case of failure?	Can cope with risks completely. Can moderately cope with risk. Will have serious problems in case of failure
Q29.	When do you expect to realize profit from the product line?	Long term substantial returns. Medium term above average returns. Incremental return in the short-term.
Q30.	To what extent can you afford to adapt the organization structure?	We can change the organization structure according to the needs for SPLE. The organization structure can be slightly changed to adopt SPLE. The organization structure is fixed, we need to adopt the SPLE process with the given organization structure.
Q31.	What's the CMMI maturity level of the organization?	CMMI 5 - CMMI 4 - CMMI 3 - CMMI 2- CMMI 1
Q32.	What's the attitude for change within the organization?	Open to change Neutral Conservative
Q33.	What's your chief architect experience?	The organization has previous experience in architecting product line systems. (high) The organization has extensive experience in architecting similar systems, but not necessarily in a product line context. (medium) The organization has limited experience in architecting similar systems. (low)
Q34.	What is the level of domain expertise in the application domain?	The company has a few years of experience and produced several products in the application domain. (high) The company has limited experience and produced at least one product in the application domain. (medium) The company is entering into a new domain. (low)

Appendix B – Identified Questions in the DSM (Continued)

Q. ID	Question	Possible Answers
Q35.	What's the level of tool support that can be used for SPLE?	High (supports SPLE development environment). Medium (supports single-system development environment). Low (support is limited).
Q36.	Do you plan to sell products to other countries?	Yes, this is explicitly planned. No such plans now, but maybe in the future. No, our products will only be domestic.
Q37.	To what extent is the product line scope defined?	We have a well-defined product portfolio and roadmap. The product portfolio is largely known but not yet committed. The product portfolio is not yet determined yet.
Q38.	How stable is the funding for the overall investment?	Funding is not a problem. We can largely afford the overall investment. We will have problems with providing the overall investment.
Q39.	What's the degree of connection with customers?	High (customers actively involved in product line requirements). Low (loose connection with customers). None (no explicit connection with customers).

Appendix C – Questions for the Interview

Question	**Question Type**	**Time of Interview**
Please provide information about the SPL candidate	General	Initial Interview
With the information at hand, are you planning to adopt SPL approach?	Decision Drift, Feasibility	Initial Interview / Post Interview
If you are planning to adopt SPL approach, which strategy do you prefer?	Decision Drift, Strategy	Initial Interview / Post Interview
What are the possible barriers to SPL adoption in your context?	Decision Drift, Feasibility	Initial Interview / Post Interview
What are the weakest points for your SPLE adoption?	Decision Drift, Feasibility	Initial Interview / Post Interview
What are the strongest points for your SPLE adoption?	Decision Drift, Feasibility	Initial Interview / Post Interview
What do you think about the validity of the recommendation provided?	Feasibility, Strategy	Post Interview
Has your decision been changed after using *Transit-PL* regarding SPL adoption?	Decision Drift, Feasibility, Strategy	Post Interview
How practical was *Transit-PL*?	Tool assessment	Post Interview
Will you use *Transit-PL* again?	Tool assessment	Post Interview
Do you have any suggestions for improving *Transit-PL*?	Tool assessment	Post Interview
What do you think about the quality of the rules / questions / recommendations?	Tool assessment	Post Interview
Does *Transit-PL* adequately measure the organization's ability to assess SPL feasibility?	Tool assessment	Post Interview
Do you think that *Transit-PL* can provide a competitive advantage to the organization?	Tool assessment	Post Interview
Has the usage of *Transit-PL* enhanced your knowledge on SPLE adoption?	Tool assessment	Post Interview
How useful was *Transit-PL* for SPL adoption?	Tool assessment	Post Interview
What do you think about the recommended transition strategy?	Strategy	Post Interview

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: Tüzün, Eray
Nationality: Turkish (TC)
Date and Place of Birth: 23 June 1978, Ankara
Email: eraytuzun@gmail.com

EDUCATION

Degree	Institution	Year of Graduation
MS	Case Western Reserve University, Electrical Engineering and Computer Science Department	2003
BS	Bilkent University, Computer Engineering and Information Science	2000
High School	Ankara Atatürk Anadolu High School, Ankara	1996

WORK EXPERIENCE

Year	Organization	Position
2008- Present	HAVELSAN, Ankara	Senior Software Engineer
2007-2008	Microsoft, Seattle	Software Development Engineer
2003-2008	Howard Hughes Medical Institute , Seattle	Research Software Engineer
2000-2003	Case Western Reserve University, Cleveland	Research Assistant

FOREIGN LANGUAGES

Fluent English

SELECTED PUBLICATIONS

E. Tüzün, B. Tekinerdogan, and S. Bilgen, "Deriving Metrics to Support Software Product Line Feasibility Analysis", in *Proceedings of International Workshop on Designing Reusable Components and Measuring Reusability*, 2013, pp. 8–9.

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