

The Design and Development of Software Process Reference Models – Experiences and Lessons Learnt

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Abstract. Software process reference models can serve as a tool for simplifying process problem solving. Through a series of research phases using sources in industry and academia, we developed a software process reference model for the derivation of products from a software product line. In this paper we describe how empirical evidence was used in the development of that process reference model while following an evolutionary multi-method research approach. A discussion on the selection of research methods for construction of process reference models is included. We explain how the different phases of the research formed a continuum in which the model was continually adjusted. Finally, we document important lessons learnt on software process reference model construction. The goal of this paper is to contribute to both the improved understanding of real world reference model construction and to the practical implementation of reference model construction guidelines.

Keywords: Software product lines, product derivation, process reference models.

1 Introduction

The main objective of a reference model is to streamline the design of (particular) models by providing a generic solution that can serve as a template for defining a model for a particular enterprise [1]. It can thus serve as a tool for simplifying process problem solving, and enables users to have a degree of confidence that the process begins on a solid foundation.

A reference model is (usually) created to represent already existing processes, e.g. by observing current practice in industry and academia, and thus serves as a blueprint for others. Reference models have to be universally applicable for a certain situation, and serve as a recommendation on how to solve or organise that situation.

The possible benefits of reference models are to raise the quality of the models produced, a cost, time and risk reduction, the reuse of knowledge, and access to industry best practices [2]. Reference models accelerate the modeling and configuration process by providing a repository of potentially relevant models [3].

Although there is a lack of empirical evidence to support these claims, it is a software engineering assumption, that when you reuse, instead of developing from scratch, a positive influence can be observed on the time-to market, product quality and development cost of the intended product. It is based on this assumption that reference models are believed to bring benefit.

According to [4] there has been a growing interest in construction approaches for process reference models. However there is a lack of real world experiences on reference model construction.

In Lero, we developed research aimed to fill an identified gap in process support for software product lines through the development of a process reference model for product derivation (Pro-PD). Pro-PD has been well received by the software engineering community with both journal [5, 6] and conference publications [7-9], and an invention disclosure by the University of Limerick [10].

The objective of this paper is two-fold: Firstly, show how an evolutionary multi-method research approach that adopted best practice reference model construction guidelines was designed and applied; and secondly, present important lessons learnt for process reference model construction based on our experience.

The paper is organised as follows: In Section 2 the research design is presented including the selection of research methods. Section 3 presents Pro-PD, the process reference model for product derivation. Section 4 discusses the lessons learnt. Finally Section 5 presents the conclusion.

2 Research Design

To define the research steps needed to construct a process reference model, the research methods must be selected. No single research method however is universally applicable and “all research approaches may have something to offer” [11]. There is a considerable range of research methods available [12], all of which have distinct strengths and weaknesses. To compensate for these weaknesses, Franz et al. [13] recommend multi-method research design. Multi-method design is “the conduct of two or more research methods, each conducted rigorously and complete in itself, in one project” [14]. By triangulating between methods and data, more plausible interpretations can emerge.

According to [15] multi-method research may be conducted from a complementary or evolutionary perspective. In the development of our process reference model, an evolutionary approach was followed. An evolutionary approach is used when there is little research conducted on a particular phenomenon, as was the situation in our case.

Rather than investigating an effect through two or more different empirical methods, seeking confirmatory power between them, an initial exploratory study gathering qualitative data is undertaken. At this early phase, the initial study is designed to explore a wide range of topics in the area under investigation. The collected data is then analysed, and the important findings from the initial study are refined and used in the study. This process is then repeated, usually using a different research method.

Therefore, we applied an evolutionary multi-method research approach. The research design adopted was influenced by an approach by Ahlemann et al. [16] and was focused on empirically grounded and validatable process reference model construction.

2.1 Overview of Research Design

In an analogy with systems engineering, the overall construction process was based on a cyclic structure to allow for model corrections on preceding construction stages via feedback-loops. Although the stages are dealt with sequentially, they contain cyclic sub-processes. The research design was compatible with common suggestions for qualitative research designs in process models [4]. Stages 1 and 2 were the primary construction steps. Stage 3 was both a development and an evaluation step. Finally, stage 4 was purely an evaluation step. An overview of the research design is presented in Figure 1.

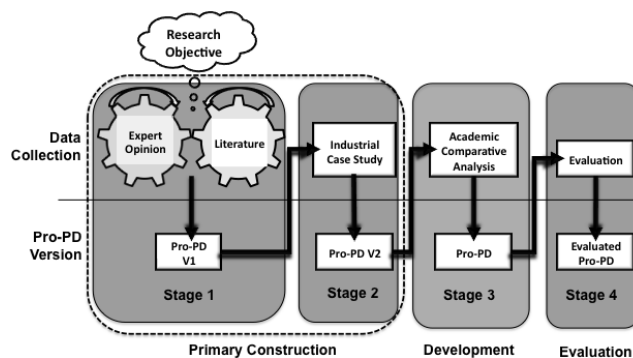


Fig. 1. Overview of Research Design

Stage 1 entailed a literature review from which a preliminary version of the model was developed. The literature review aimed to identify the fundamental practices of product derivation, through studying existing identified product derivation approaches. Concurrent to the literature review, a series of iterative expert opinion workshops was organised. Participation by expert users in the core construction stage is emphasised by Rosemann and Schütte [17] and Schlagheck [18], as the users are the subject-matter experts of the problem domain. Furthermore, as the research is designed for use in both industry and academia, the selection of experts should reflect this. With this in mind, the selected participants were two academic SPL experts with

20 years’ experience, an industrial SPL expert with 10 years’ experience and a software process improvement expert.

Participants met twice a month for six months. At each workshop the reference model was presented to the experts and was evaluated using formal questions on model structure. The model was discussed amongst the group until a consensus was formed and the model was revised. After each workshop we returned to the literature and based upon the expert revisions and secondary research, iteratively developed the reference model.

Stage 2 was an industrial case study within Robert Bosch GmbH. This was carried out as an inductive, empirical validation [16]. We chose a case study as they are often considered to be the optimal approach for researching practice based problems, where the aim is to represent the case authentically “in its own terms” [19]. The reference model was mapped and compared to product derivation practices within the company. Robert Bosch GmbH was chosen for the case study because previous SPL efforts had been judged a success by their peers [20]. The case study was carried out in conjunction with the corporate research division. The case study was dual-purpose. In the first instance, we modelled the Bosch product derivation process for their internal use and then we updated the reference model based on our observations.

In conducting the case study, we analysed internal company documentation, which illustrated the existing process through completed projects. We then organised an onsite visit including a two-day workshop with the corporate research division of Robert Bosch GmbH. Attendees included selected product architects and developers from product line business units within the company. The primary researcher (O’Leary) was accompanied by two other researchers, one of whom had published extensively on case study research. After the workshop, a technical report [21] on the company’s product derivation process was created and validated through feedback with Bosch SPL experts. Both the documentation analysis and the workshop output were used to identify what components should be included in subsequent versions of the reference model.

Stage 3 of the research, an academic comparative analysis, was carried out during a research collaboration with JKU (Johannes Kepler University Linz, Austria). JKU had previously developed the DOPLER^{UCon} (**D**ecision-**O**riented **P**roduct **L**ine **E**ngineering for effective **R**euse: **U**ser-centered **C**onfiguration) approach. Based on initial discussions and existing documentation of our two approaches, a high-level mapping was created. This was done in a distributed manner using spreadsheets to visualize commonalities and differences between the two approaches. Using this mapping, the researchers met to analyse the first results, discuss open issues, and detail the comparison. We then conducted several telephone conferences with JKU researchers to work on the details of the comparison. Pro-PD was compared to the activities identified by DOPLER for Siemens VAI. Based on this comparison [5, 8] the final version of the model, Pro-PD, was developed.

Pro-PD was evaluated in two steps during stage 4 of the research. The first was an inter-model evaluation with the SEI PLPF [22] during which Pro-PD was reverse engineered and compared to the PLPF. According to Ahlemann et al. [16] process models that are compatible with such standards and norms can be regarded as high quality. Then, we systematically evaluated Pro-PD by analyzing support for its activities in three independently developed, published and highly-cited approaches:

COVAMOF [23], FAST [24], and PuLSE-I [25]. The approaches have been developed with different goals, for different purposes, and in different domains. Furthermore, in our literature review we identified that these three approaches were influential through their frequent citations.

Although a framework for evaluating product derivation approaches does not exist, we adapted a framework developed for the purpose of evaluating software product line architecture design methods [26]. We used this framework as a basis for our validation for two reasons. Firstly, it provided a simple tabular evaluation structure. Secondly, it had previously been published at ICSE, which ensures that it has been peer-reviewed.

3 Result of Research - Pro-PD

As a result of the described research design, Pro-PD, a process reference model for product derivation was developed. Pro-PD focused on the roles, work products, tasks and activities used to derive products from a software product line. These elements represent the process building blocks of Pro-PD. Fig. 2. gives an overview of these Pro-PD activities and the iterative nature of the Pro-PD process.

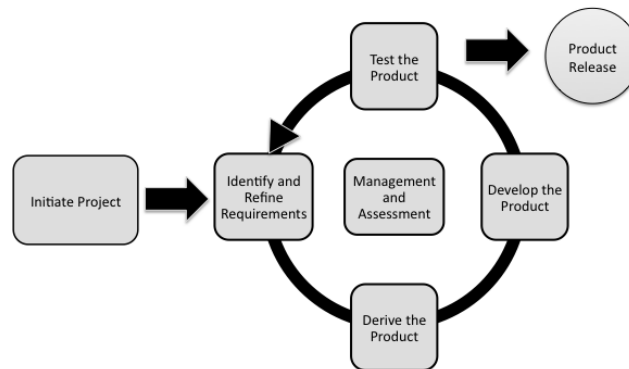


Fig. 2. Overview of Pro-PD Activities

3.1 Units of Work: Tasks and Activities

Pro-PD contains the following activities:

- **Initiate Project** - the preparatory tasks required to establish a product derivation project.
- **Identify and Refine Requirements** – the preparatory tasks required to commence a new iteration of the product derivation project.
- **Derive the Product** - creates an integrated product configuration that makes maximum use of the platform and minimises the amount of product specific development required.

- **Develop the Product** - facilitates requirements that could not be satisfied by a configuration of the existing assets through component development or adaptation.
- **Test the Product** - validates the current product build.
- **Management and Assessment** - provides feedback to the platform team and monitor progress of derivation project.

Table 1 lists the tasks performed for each of these activities:

Table 1. Pro-PD Activities and Tasks

Activity	Tasks performed in this activity
Initiate Project	Translate Customer Requirements; Coverage Analysis; Customer Negotiation; Create the Product Requirements; Verify the Product Requirements
Identify and Refine Requirements	Find and Outline Requirements; Create the Product Test Cases; Allocate Requirements; Create Guidance for Decision Makers
Derive the Product	Select Closest Matching Configuration; Derive New Configuration; Evaluate Product Architecture; Select Platform Components; Product Integration; Integration Testing; Identify Required Product Development
Develop the Product	Component Development; Component Testing; Product Integration and Testing
Test the Product	Run Acceptance Tests
Management	Provide Feedback to Platform Team, Monitor Project

3.2 Roles

We identified roles that represent the different responsibilities, which occur during product derivation: Customer, Product Analyst, Product Architect, Product Developer, Product Manager and Product Tester. These roles are assigned to specific tasks, which create and modify the different work products.

Table 2. Roles and Responsibilities

Role	Responsibilities
Customer	Customer Negotiation, Create Guidance for Decision Makers
Product Analyst	Translate Customer Requirements, Find and Outline Requirements,
Product Architect	Derive New Configuration, Select Closest Matching Configuration, Integrate and Create Product Build, Integration Testing, Provide Feedback to Platform Team
Product Developer	Select Platform Components, Develop/Adapt Components, Component Unit Testing
Product Manager	Coverage Analysis, Customer Negotiation, Create the Product Specific Requirements, Assess Results, Provide Feedback to Platform Team
Product Tester	Create the Product Test Cases, Integration Testing, Run System Tests

3.3 Work Products

Table 3. Work Products

Software Artefact	Platform Test Artefacts, Product Build, Product Test Cases, New Platform Release, Platform Architecture, Platform Components, Developed or Adapted Components, Existing Platform Configurations, Base Product Configuration, Integrated Product Configuration,
Documentation	Required Product Development, Translated Customer Requirements, Product Specific Platform Requirements, Product Requirements, Platform Feedback, Platform Requirements, Customer Requirements, Customer Specific Product Requirements, Negotiated Customer Requirements, Glossary,

A work product is an artefact, which is produced, modified or used by a task within the derivation process. The list of Pro-PD work products is listed in **Table 3**.

3.4 Pro-PD as a Reference Model

Pro-PD is defined at a high level and is not to be used ‘as is’ but through specialization. In order to create a working company specific model the process needs to be specialized and a lower level of model abstraction needs to be constructed. Different instantiations of Pro-PD are created by following the adaptation rules and using the roles, tasks, activities and work products defined. We demonstrate the adaptability of Pro-PD as a reference model by proposing a waterfall instantiation [27] and an Agile instantiation (A-Pro-PD) [6].

4 Research Validity

All research only becomes valuable when it is first deemed credible. Many authors such as Creswell [28] however point out that there is no consensus or right way of verifying the credibility of qualitative research. In this context, Marshall [29] argues that the quality of research is dependent on honest and forthright investigations. This dependency means it is difficult to verify the quality of qualitative research. Another difficulty in qualitative research is the introduction of bias and the danger of multiple interpretations of data. Therefore, a self-critical attitude is essential in qualitative research. Demonstrating how you know is as important as demonstrating what you now.

4.1 Ensuring integrity, validity and accuracy of the results

Internal validity and credibility is achieved through prolonged engagement in the field, persistent observation and triangulation exercises [30, 31]. From their discussions on triangulation, Liamputtong and Ezzy [32] identify four types of triangulation, which may be used to strengthen a potentially weak case:

- Data Source Triangulation: The use of multiple information sources.
- Method Triangulation: The application of findings generated by different data collection methods.
- Researcher Triangulation: The inclusion of a variety of researchers in the research process.
- Theory Triangulation: we draw on multiple theoretical perspectives to provide new insights.

This research uses data source triangulation. In the initial framework development, multiple sources of literature were used as well as anecdotal evidence from SPL experts. Industrial practice was integrated directly through case study research and indirectly through the experiences of DOPLER^{UCon}. In the Robert Bosch GmbH case study multiple data sources were used. In the DOPLER^{UCon} academic comparative analysis, we had access to documentation and to the developers of the approach.

The research uses method triangulation. The research design includes case study research, expert opinion, facilitated workshops and SPL literature.

The research uses researcher triangulation. When it was possible the services of other researchers to facilitate the main researcher were engaged. In the facilitated industrial case study workshop session two other researchers assisted in the organisation and recording of results in the workshop sessions. During the collaboration with JKU, the research involved two members of the DOPLER^{UCon} team.

The research uses theory triangulation. In the development of the initial version of Pro-PD, we used a multitude of evidence from literature to theoretically validate aspects of the model. We synthesised this existing theory. This is a form of theory triangulation.

Another method of strengthening credibility is through respondent validation [33]. Lincoln and Guba state that respondent validation is “the most critical technique for establishing credibility” [31]. In respondent validation, we went back to the subjects with tentative results and refines them in light of their reactions. In Section 2 we describe how respondent validation was used during the iterative development of the model in the expert opinion workshop series. In the academic comparative analysis, the results were validated by the DOPLER^{UCon} team.

5 Lessons Learnt

Based on our experiences, we have detailed a number of important lessons for process reference model construction.

5.1 Choose an Appropriate Description Level

A common mistake in process reference model construction is over detailing the process. Often, due to over enthusiasm, process designers specify the most minute tasks to be performed – such process are virtually impossible to verify. Furthermore, once the process is implemented it is impossible to verify if these minute tasks were

performed. Each process step should be defined at an appropriate level with clearly identified inputs and outputs, which can be used for performance verification.

A distinction should be made between a descriptive and prescriptive process description. In this regard, it is best to separate guidelines and checklists from processes. For example, detailed prescriptive process steps are better kept as guidelines or checklists. However, descriptive task listings should be applied and can be validated by an external auditor.

This makes the process reference models simple and more stable, while providing flexibility at the lowest level by providing different checklists and guidelines. Keeping the reference model simple makes it verifiable and minimizes the desire by practitioners to “fake it” by pretending to conform to some over strident process task requirements.

5.2 Documentation of Design Decisions

The construction process is normally not documented in reference modelling projects [16]. Therefore, it is often not clear how the final design of the reference model came to be. A reference model is only as strong as the design decisions taken in its construction; therefore documentation of design decisions is an essential element in proving the quality of a reference model.

Typically from reviewing the design decisions, the different flaws for each version of a reference model can be identified. The purpose of the different research development iterations is to sort out the weak as well as the strong parts of the process reference model. The important answers to capture are how, why and what impact these research stages have had on the model design.

5.3 Handling Refinements

Each stage of the research provides the basis for the revision or refinement of the reference model. A major challenge when performing development iterations is the evaluation of different suggestions with respect to each other. For example, before a correction is integrated it has to be determined whether the proposal can be characterized as being universally valid or whether it is tied to a specific context and therefore not suitable for model refinement.

Furthermore, improvement suggestions made by different persons are sometimes contradictory. There were two options to resolve these situations. First, one proposal is chosen over another if the source was deemed to be of a better quality, either through its experience or the location of the source. This evaluation is conducted by the researcher, and involves a degree of researcher interpretation as to the quality of the various sources. The alternative approach is to consider both suggestions and integrate them both into the model.

5.4 Outside Involvement

As described in Section 2, participation of process users in the core construction stage is essential, as the users are the subject-matter experts of the problem domain. Therefore, to define a process, it is best to have a task force that consists primarily of users of the process, and which is given some high-level guidelines and requirements

While defining a reference model, it is best to “standardize” current processes that are being practiced. In other words, it is best to leverage the experience in outside organizations to define processes rather than suggesting the ‘from scratch’ adoption of an external process reference model. In our research approach, we first standardised the product derivation process within Robert Bosch GmbH, before integration of Pro-PD. Frequently, for many of the problems, solutions have already been found within the organization. In these situations, the task of process definition becomes identifying the solutions and then “packaging” them properly for a wider use.

5.5 Generalizing the Findings

The ability to generalise is a key component of process reference model construction. However, this can often be challenging, particularly when your research design involves qualitative methods. As Patton [34] points out that the small size involved in qualitative methods make it impossible to generalise the results. This can be especially true in case study research where the focus on a particular case makes it unable to produce a general conclusion.

In an effort to counteract any weakness a multi-method research design should be adopted. By considering different sources such as expert opinion, literature, case studies and documented best practice, the generalisability of a reference model can improve and more plausible interpretations of the data can emerge.

6 Conclusion

This paper discusses how reference modeling projects, such as the development of Pro-PD, can be based on an empirically grounded and verifiable process. The discussion surrounding the selection of appropriate research methods is described, the application of the selected methods is detailed and the important lessons learnt are documented.

The paper contributes to an improved understanding of real world reference model construction through documenting our experiences and approach. This example from a completed research project contributes to the practical implementation of reference model construction guidelines.

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