Variability Management in Software Product Lines: An Investigation of Contemporary Industrial Challenges

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Abstract. Variability management is critical for achieving the large scale reuse promised by the software product line paradigm. It has been studied for almost 20 years. We assert that it is important to explore how well the body of knowledge of variability management solves the challenges faced by industrial practitioners, and what are the remaining and (or) emerging challenges. To gain such understanding of the challenges of variability management faced by practitioners, we have conducted an empirical study using focus group as data collection method. The results of the study highlight several technical challenges that are often faced by practitioners in their daily practices. Different from previous studies, the results also reveal and shed light on several non-technical challenges that were almost neglected by existing research.

1 Introduction

Software intensive systems in a certain domain may share a large amount of commonalities. Instead of developing each product individually, software product line engineering looks at these systems as a whole and develop them by maximizing the scale of reuse of platforms and mass customization [20]. Thus, it is claimed that Software Product Line (SPL) can help reduce both development cost and time to market [15]. A key distinction of Software Product Line Engineering (SPLE) from other reuse-based approaches is that the various assets of the product line infrastructure contain variability, which refers to the ability of an artifact to be configured, customized, extended, or changed for use in a specific context [3]. Variability in a product line must be defined, represented, exploited, implemented, and evolved throughout the lifecycle of SPLE, which is called Variability Management (VM) [15]. It is a fundamental undertaking of the SPLE approach [15].

VM in SPL has been studied for almost 20 years since the early 1990s. Feature-Oriented Domain Analysis (FODA) method [10] and the Synthesis approach [11] are two of the first contributions to VM research and practice. Since then diverse methods/approaches have been proposed [7]. The goal of all these research efforts should be to help practitioners to solve their real problems. Hence, there is a vital need to explore how well the VM body of knowledge solves the problems faced by industrial practitioners, and what are the remaining and (or) emerging issues. Such an effort can help to update the understanding of issues and VM challenges in SPL practice. Such an understanding is expected to help researchers to direct their research efforts towards real and high priority issues and challenges in the industry, and thus can provide practitioners with more support for VM and improve their productivity. As such, the specific research question that motivated this study was:

- What are the contemporary industrial challenges in variability management in software product lines?

The goal of this paper is to report the results of an empirical study aimed at identifying issues and challenges of VM in SPLE faced by industry practitioners. This paper is organized as follows. Section 2 provides the details of the research methodology used for this research. Section 3 presents the findings of this study. Section 4 discusses the findings from analysis of the data gathered during the focus group discussions with respect to the published literature on variability management in software product lines. Section 5 mentions some of the potential limitations of the reported study and its findings and Section 6 finishes the paper with a brief discussion about the outcomes from the reported study and future work in this area.

2 Research Method

We conducted an empirical study using focus group research method in order to identify the issues and challenges of VM in SPLE faced by industry practitioners in their daily activities. We decided to use the focus group research method because it is a proven and tested technique to obtain the perception of a group of selected people on a defined area of interest [1, 13, 24]. In the following sub sections, we describe the process of this study according to the five steps involved in the focus group research method.

2.1 Define the Problem

In this step, we defined the research problem that needed to be studied by using the focus group research. The research problem was derived from our research goal (i.e., to gain an understanding of issues and challenges of VM in SPL in practice) as described in Section 1.

2.2 Plan Focus Group

In this step, we set the criteria for selecting participants, decided the session length, designed the sequence of questions to ask during the session[1], and prepared documents to provide the participants with the study background, objectives, and protocols.

[1] One of our colleagues also participated in designing the sequence of questions to ask during the session.

2.3 Select Participants

In this step, we selected participants according to the criteria devised during the planning stage. In order to gain insights into the VM challenges in practice, we followed the following criteria for selecting the participants:

- experience of variability management in practice,
- knowledge and expertise of issues/challenges of variability management, and
- willingness to share their experiences and candid opinion.

According to the selection criteria, our study needed practitioners with industrial experience in VM in SPLE. Such practitioners are usually very busy and are not likely to respond to invitations from unfamiliar sources. Thus, a random sampling was not viable.

Consequently, we decided to use availability sampling, which seeks responses from those who meet the selection criteria and are available and willing to participate in a study. The International Software Product Line Conference (SPLC) attracts a large number of practitioners every year. We sent invitation emails to practitioners who were going to attend SPLC 2008 and met our selection criteria.

2.4 Conducting the Focus Group Session

We held three focus group sessions, each of them lasting approximately one hour. The flow of the discussion was designed to be as natural and as easy to follow as possible. Each session started with a brief introduction of the participants and researchers. Then the discussion flowed through a predefined sequence of specific topics related to the challenges in different phases of SPLE, i.e., requirements phase, architecture phase, implementation phase, testing phase, and any other aspect of VM in SPLE. The separation between phases is based on the SPLE framework presented by Pohl et al. [20]; however, to not complicate the discussion flow, we decided not to separate the discussions on domain engineering and application engineering in each phase. The sessions were audio recorded with the participants' consent.

2.5 Data Analysis

In this step, we transcribed the recorded discussion and coded the transcription. The focus group sessions of this study resulted in approximately three hours of audio recording. The audio recording was transcribed by transcribers. In order to verify that there was no bias introduced during the transcription, the first researcher randomly checked several parts of the transcription. No significant differences were found.

To analyze the transcribed data, we performed content analysis and frequency analysis. We followed the iterative content analysis technique, which is a technique for making replicative and valid inferences from data to their context [14], to prepare qualitative data for further analysis. During content analysis, we mainly used Strauss and Corbin's [26] open coding method. With this method, we broke the data into discrete parts, and closely examined and compared them for similarities and differences.

Data parts that are found to be conceptually similar in nature or related in meaning were grouped under more abstract categories. The coding was performed by the first researcher and checked by the second researcher.

To identify the relative importance of the challenges' influence on industrial practices in variability management, we performed frequency analysis on the transcribed data for the high level themes.

3 Results

In this section, we present the results of the study. We first present the demographics of the participants, then present the issues reported by the participants, and finally describe the frequency analysis.

Table 1. Demographic information about the participants

ID	Title	Experience	Country	Domain	Company size	Type of company
1	Principle member of research staff	8+ years in SPL; has been working with 40 SPLs.	Finland	Mobile phones	112,262	In-house
2	Senior member of the technical staff; Principal	Worked in SPL since 1990; consulted various companies.	USA	Various	<50	Consultant
3	Project manager in SPL	5 years in SPL	Spain	Embedded	51-200	Consultant
4	Software engineer, SPL supporter	SPL initiative started about 6 or 8 months	USA	Defence, aerospace	106,000	In-house
5	Chief software architect.	20 years in SE; 7 years in SPL	USA	Embedded	73,000	In-house
6	Software architect and software development process manager	Introduced the SPL approach 4 months ago;	Germany	Embedded	4,000	In-house
7	Director	10 years in SPL; consulted various banks and insurance companies	Australia	Finance	40	Consultant
8	Research scientist	Work three days per week in the company since 2004	Netherlands	Healthcare	123,801	In-house
9	Software architect	25+ years in SD; around 5 years in SA and SPL.	USA	Embedded	263,000	In-house
10	Global software process and quality manager	6 years in SPL	Switzerland	Embedded	128,000	In-house
11	Senior scientist	About 8 years in SPL	Netherlands	Embedded	33,500	In-house

3.1 Demographics and Frequency of Participants' Participation

Table 1 shows the profile of the participants of the focus group sessions. There were 11 participants in the focus group sessions. The majority of them were holding senior positions in their respective organizations and were playing important roles (e.g. responsible for, advocator, and introducer) in their organizations' SPL adoption and management practices. The participants also had good knowledge of their companies' SPL initiatives. It is worth to note that some of them had the title of "researcher"; however, they were working in research centers in industrial companies rather than academic research institutes. They usually had good knowledge of the VM challenges in their organizations. So we considered them as SPL practitioners in this study.

Each of the participants came from a different company. These 11 companies varied in type, size, domain, and geographical area. While the majority of the companies were in-house development units, there were also three consultancy companies. All the in-house development companies were of large size in terms of the number of employees[2]. The consultant companies were of a small to medium size; however, the participants from these three consultancy companies had worked with various other large companies, so they brought in their experience with those various companies as well. The majority of the participants' companies were working in embedded systems; however, there were also representatives from other domains like finance and telecommunications. The companies where the participants came from are located in seven different countries covering three continents (i.e., America, Europe, and Australia).

The demographics information about the participants of our study gives us confidence that we gathered data from practitioners who were knowledgeable about VM challenges based on their experience in practice. Furthermore, although the number of the participants is not high, they came from 11 different companies (most of them had extensive experience in VM) and 7 different countries. So their views can be considered representative of the VM challenges faced by broad practitioners in industry with similar characteristics.

Table 2 summarizes the amount of participations by each participant. The number in the cell indicates the number of speeches from a particular participant. It can be observed that there were no dominant speakers during the discussion. Every participant got almost equal opportunity to share his/her experience and opinion on different aspect of VM in SPL.

Table 2. Frequencies of speeches by each participant

Participant ID	1	2	3	4	5	6	7	8	9	10	11
Frequency of speeches	43	41	19	37	37	29	25	21	31	31	40

[2] We used the European Commission SME definition: companies with 250 or more employees are considered as large size, companies with 50 (inclusive) to 250 employees are considered as medium size, and companies with 10 (inclusive) to 50 employees are considered as small size. http://ec.europa.eu/enterprise/policies/sme/files/sme_definition/sme_user_guide_en.pdf

3.2 Challenges Faced by Practitioners in Variability Management

The focus group discussions mainly followed the life cycle stages of SPLE, as we mentioned in Section 2.4. However, when we were analyzing the results, we found that the majority of the issues/challenges reported by the participants are not particular to a specific phase. Therefore, we decided not to organize our reporting of the results follow the life cycle stages of SPLE. Instead, we divided them into two categories: technical issues and non-technical issues. The issues we found are summarized below.

3.2.1 Technical Issues

Handling complexity: When discussing issues in the requirements phase, the participants reported that handling the complex variability is challenging. One participant mentioned that, "when you have 300 features it is very difficult to visualize…so for us it's not easy to visualize features and show that to the customer." Maintaining complex variability models is also challenging. As one participant responded, "I mean there's no way to maintain it, I mean the maintaining, especially changing those decisions, is extremely hard because the chances that you break something is very high, because the context that you try it in is huge." The participant also commented that the research output from intelligent decision models area is far away from being applicable to the real industrial settings.

When discussing issues in the implementation phase, the participants reported that for the variability that was a bunch of numbers is relatively easy to manage, but for the variabilities that are much more complex than numbers are difficult to manage. One participant said, "but other things are much more complex, e.g., certain types of algorithms, or whatever there might be in our systems …that's not something that we know how to do very well yet…."

Knowledge harvest and management: When discussing issues in the requirements phase, several participants mentioned that a more challenging task than how to represent the variability (e.g., using feature models) is how to harvest and share the knowledge in an efficient way. They said that the technical artifacts (e.g., source code, design, and requirements specifications) are so diverse, there is no single repository where practitioners can find the required information; abstracting the requirements of different systems into a coherent and consistent variability model is challenging. Understanding the implications of different features on customers' buy-in, on the software product line architecture was also reported to be challenging.

Extracting variability from technical artifacts: The participants reported that in the situation that the software product line is built on similar pre-existing systems, extracting the variability and commonality of those systems from the various artifacts is challenging.

The same is true in the architecture phase, the participants reported that extracting the variability from technical artifacts of different similar products and building a common architecture for those products are challenging. One participant said: "We recently did [a] kind of a workshop where we took one single piece of code. Several senior architects looked at it. It took almost five or six hours just to go through one file. There were several thousands of lines of code. We tried to figure out why were these decisions made and how can we decouple and componentize this piece of software…because it is such a legacy system and there are so many variants, it's hard to tell the common places versus the points of variability".

On implementation level, the participants reported that in the situation where different similar products were developed using clone and own practices heavily, extracting the variability from the source code files is challenging. There are some clone detection tools but they have been developed mainly for single systems. If there are multiple code bases, each for one product, comparing them and extracting out variability from them is very difficult. Componentizing the existing code and building variability inside and around them are challenging.

Evolution of variability: The participants reported that in SPLE paradigm, SPLE requirements span different systems. These systems inevitably evolve over time. So the variability exists not only over space (change from system to system) but also over time (change over time). Managing the evolving requirements of SPL is challenging.

When requirements changed, in some cases, the existing architecture does not support the required variability in the new requirements. Some participants mentioned that, in an extreme case where the product line started with one single product, evolving the architecture towards a software product line is really an issue. One participant reported that initially, the company just wanted to penetrate the market with one single product without any variation. Then the product would grow over time and this also meant the architecture needed to be changed. Small changes and variation points were added gradually. After a couple of years, the architecture did not work anymore. Participants said they had not come across good solutions for such challenges. In some domains (e.g., mobile phones), the extending problem (extending the scope of product line) is evident. Some typical evolution scenarios include: adding variation points and variants, removing obsolete variation points and variants, changing relationships among variation points and variants.

Variability modeling and documentation: The participants mentioned that the variability modeling approaches are not very user friendly. How to document variabilities in a way that is easy to understand and use by different stakeholders is an issue. The participants also reported that compared to the structural aspects, managing the variability in the behavioral and timing aspects is more challenging and less solved.

Design decisions management and enforcement: The participants reported that managing architectural design decisions and enforcing those decisions are challenging. For example, one participant reported that the architecture design decisions were documented in Microsoft Word document, but they are very difficult to find by the related stakeholders. A better strategy to find these documented decisions is needed. The participant also reported that understanding how the alternative decisions can lead to different architectures, and what the implications of those decisions are on the resulting systems is a key challenge. One participant said: "understanding how to do that properly really requires a lot of experience with systems of that type actually."

Tool support: The participants reported that there is a lack of sufficient tool support for managing variability. One participant said: "it [the tool] works pretty good for specific individual projects that you're going to deliver but for maintaining core assets it doesn't…you know…you have to get creative as far as how to manage variability in requirements." Two participants also reported the difficulties of integrating their chosen requirements management tool (i.e. DOORS) with currently available variability management tool. One participant said there was a tool change step from DOORS to one of the available variability management tool, so they had to develop a connection between those tools. But finally due to the fact that they cannot afford to maintain the home developed connection, it was not used. They agreed that developing and especially maintaining home grown tool is too costly. The participants expressed their expectation to have an integrated, standardized, and end-to-end tool support, instead of having different tools for closely related problems.

Testing: The participants reported that testing variability in SPL is a challenge, which can cause several problems. Large amounts of efforts are spent on software testing in industry, but they could not see much effort from researchers. For example, one participant said "If you see in practice, many people - a third or something on testing, a quarter, should be even more probably – but then if you look at the same amount of people in research […] I don't know how many percent of the researchers are really working on testing." One participant also mentioned that there is little, if any, work on testing the quality of the core asset to see how it is flexible enough to support the variations, instead of testing the products that come out of the core asset.

3.2.2 Non-Technical Issues

People: During discussion of the issues in architecture phase, the participants reported that having good architects is essential for developing and maintaining a software product line architecture. However, there is a lack of good architects who are good at thinking at an abstract level, who know the mechanisms to make the architecture extensible and flexible, and can apply those principles in practice. The architects should also have a product line mindset. With this mindset, rather than architecting their new variability in a sense that it is their own product, architects are going to be architecting the new variability in a mindset that it has to fit on the platform that is already in existence without the clone and own approach.

Mindset change: The participants reported that changing employees' mindsets of building a single system to the mindset of building a family of systems is really challenging. One participant said: "the biggest problem you have really is people having the traditional mindset of building a single system and they have difficulties just talking about variation. […] just having a framework for getting people to think about things in a broader set is really the biggest challenge you have."

Management support: When discussing issues in the architecture phase, the participants reported that to keep the architecture from deterioration, sustained support from the organization (e.g. management support and required funding) is essential. However, keeping such sustained support can be challenging. These challenges generally include examining why certain managers accept and support VM, and what are the factors that can convince managers to give sustained support.

Organizational structure: The participants reported that the separation of the core asset team and the product team puts the people in the product team working in the situation where they have less choice. Getting them to accept the architecture that they did not design themselves is challenging. Proper communication mechanisms should be put into place to alleviate this issue. Some participants also reported that within their organization, barriers exist between different departments who own different yet similar products, and they do not talk to each other, which makes organizational changes very challenging.

Business model: The participants reported that smooth application of VM practices relies on a proper business model. For example, one participant said "Our business model is probably one of our biggest challenges… the specific customer we work with has a hierarchy where they don't talk to one another and so they are not incentivized to share assets and so we kind of mirror that. And so the business model is probably the biggest challenge we have in a sense that we are paid by lines of code not how effective we share asset." Obtaining a suitable business model is challenging when the existing business model does not encourage reuse.

3.3 Frequency Analysis

During the coding process, five high level themes emerged. They are "Technical (Tech)", "Business (Biz)", "Managerial (Mng)", "Organizational (Org)", and "People". Each of these themes corresponds to one type of issues. For example, Tech corresponds to technical issues and Biz corresponds to business issues. To determine the relevant importance of these five different types of issues to the VM industrial practices, we performed a frequency analysis. Table 3 shows the results. The number in each cell represents the number of segments of speeches associated with the theme represented by the column header. It can be seen that the sum of frequency for non-technical challenges is close to technical challenges (i.e., 10+5+8+13=36, which is close to 38). These findings indicate that non-technical challenges have significant impact on VM practices. One participant also reported that: "non-technical challenges are at least as important and difficult as those technical challenges."

Table 3. Frequecies of discussion on each type of issues

Type	Biz	Mng	Org	People	Tech
Frequency	10	5	8	13	38

4 Discussion

We discuss our findings in the context of (relation to) the research output in VM research (a similar approach was used by Rabiser et al. [22]). Specifically, by research output we refer to the VM approaches proposed in the literature. Some of these approaches have been systematically reviewed from different angles and purposes and reported in our different publications [2, 5, 7-8]. The focus of the discussion in this section is to discuss the findings from the focus group in light of the findings from literature reviews we have already reported in order to highlight the issues that still remain unsolved according to the perceptions of the participants of our study.

To facilitate the discussion, we have clustered the issues into two groups based on the number of approaches reported in the literature [2, 5, 7-8]. The two groups are shown in Table 4. The first group contains the issues for which no or only few approaches have been proposed. The second group contains the issues for which several or many approaches have been proposed.

Table 4: The grouping of issues based on the number of approaches tried to tackle them

No/few approaches have been proposed	Several/many approaches have been proposed
– People – Mindset change – Management support – Organizational structure – Business model – Handling complexity – Knowledge harvest and management – Evolution of variability – Design decisions management and enforcement – Extracting variability from technical artifacts – Testing	– Variability modeling and documentation – Tool support

The issues in the first group identify the research areas that appear to have not been given enough attention from VM researchers despite practitioners reporting that they face these issues in their daily work and feel frustrated about not having an effective and efficient solution to address these issues.

It is obvious that the challenges belonging to the non-technical issues (i.e., people, mindset change, management support, organizational structure, and business model) category appear to have received significantly less attention from the research community; none of the approaches we reviewed have tried to address any of them according to the findings from one of our literature review studies [7]. From these findings, it can be concluded that a large majority of the VM approaches nearly exclusively focus on technical aspects of VM to the extent of ignoring the VM challenges caused by non-technical factors involved such as business contexts and organizational environments. Similar observations have been made in the area of architectural description languages [17]. Encouragingly, researchers have recently begun to pay more attention to these issues by discussing them at community events [23].

So far technical challenges of VM are concerned, the issues of handling complexity, knowledge harvest and management, evolution of variability, design decisions management and enforcement, extracting variability from technical artifacts, and testing have not received sufficient attention from VM research community either. For example, extracting variability from technical artifacts has been reported as a significant challenge by the participants of our study. However, existing approaches for identifying variability (e.g., FODA [10] and DRM [19]) mainly rely on a manual process. Testing is also reported as a big challenge by the participants but there are only a few approaches for addressing testing issue exist (e.g., the ScenTED [21]). However, ScenTED does not test the core asset to see how it is flexible enough to support the variations as specially mentioned by the participants. Evolution of variability is also reported as one of the challenges by the participants; however, only three approaches, FDL [27], Ye'05 [28] and Loesch'07 [16], which are concerned with evolution of variability were found. These approaches only provide very limited support for evolution of variability, a systematic approach to provide a comprehensive support for variability evolution is not available. Handling complexity of variabilities (e.g., the huge number of variabilities and the complex relationships among them, and the complex unit of variability) has also been reported as a big challenge. Existing approaches all seem to fall short of scaling up to handle complex variability satisfactorily [6]. Encouragingly, researchers have begun to pay more attention to some of these issues by organizing community events [12] to discuss various ways of addressing the issue of handling complex variability have been held.

The issues in the second group mainly reveal/reflect the limitations of existing approaches, because although many approaches have been proposed to tackle them, practitioners are still facing these issues. In other words, the existing approaches that attempt to address those issues have several limitations, which hinder practitioners from fully utilizing (or benefiting from) them. The approaches addressing the variability modelling and documentation issue account for a large portion of the approaches we found [2, 7]. Even the standardization of variability modelling has been initiated [9]. However, as reported by the participants of our focus group, these approaches are not very user friendly. How to document variabilities in a way that is easy to understand and use by different stakeholders is still an issue. In addition, managing the variability in behavioral and timing aspects is less solved and more challenging compared to structural aspects.

Many tools have been proposed for managing variability. Even some commercial tools (e.g., Gears[3] and pure::variants[4]) have been available. However, practitioners expect to have an integrated, standardized, and end-to-end tool support, instead of having different tools for closely related problems. Such requirements have not been met, and practitioners are still suffering from this issue.

The issues in the second group call for more research to improve existing approaches or propose new approaches for satisfying practitioners' requirements.

In the above discussion, we assumed that the participants' statements on the contemporary VM issues are correct (i.e., all issues that reported in Section 3.2 and classified in Table 4 are open issues). There is a possibility that some issues that the participants reported as issues are actually not issues as practitioners may not be fully aware of the solutions to those issues proposed by the research community. We paid attention to this aspect when we were analyzing the data. We did not find such situation (based on our literature review results). This might be because the participants of our study were selected from the attendees of SPLC conference, so they tend to be aware of the recent work reported on VM research.

The findings from this study can also be used for performing comparative analysis with previously identified VM challenges such as reported in Bosch et al. [4]. Such comparison can provide useful information that would confirm the significance and relevance of the VM challenges or indicate the less importance or resolution of certain VM challenges identified many years ago. Our comparison[5] of the findings from this

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[3] A tool from BigLever (http://www.biglever.com/)

[4] A tool from the pure-systems GmbH (http://www.pure-systems.com/pure_variants.49.0.html)

[5] We have performed a similar comparative analysis in which the data from this study and Bosch et al. [4] were also used. The findings from that comparative analysis have been published in [2].That comparative analysis was performed using a coding scheme defined at a higher level of abstraction than the one

study and the VM issues reported by Bosch et al. [4] has revealed interesting information. Our analysis of the practitioners' views have discovered the issues that were not reported by Bosch et al. [4]; while we have also noticed that some of the issues mentioned in [4] were downplayed by the participants of our focus group. For example, many of the identified issues of non-technical nature (e.g., mindset change, management support, organizational structure, and business models) were not particularly emphasized in Bosch et al. [4]; nor these issues appear to have gained significant attention from other VM researchers as mentioned in Table 4. We also noticed that some of the VM issues described by Bosch et al. [4] (such as "first class representation of variability", "late binding decisions", or "stakeholders concept overlap") were either ignored or less emphasized by the participants of our focus group study. One possible interpretation of this can be either those issues are not that much important anymore or they have already been sufficiently resolved by existing VM approaches. For example, the issue of first-class representation seems to have been solved, because many approaches (e.g., COVAMOF [25] and OVM [20]) have advocated first-class citizenship of variability. However, it is difficult to make any conclusive remarks about our comparative findings because some of the VM challenges identified by others might have gone unmentioned because our sample size was too small to be expected to cover an exhaustive list of VM challenges.

In summary, the findings from this study provide useful information about and practice-based insights into the VM challenges in SPLE. These findings also not only confirm many of the VM issues reported by Bosch et al. [4] but also identify more challenges that practitioners appear to face while managing variability in SPL. Many VM challenges discovered by analyzing the perceptions of the participants of this study tend to be neglected by the VM researchers. This study has also revealed that some of VM issues reported by Bosch et al. [4] might have been solved; for example, the participants did not mention any problem in "first-class representation of variability", which was reported as a challenges by Bosch et al. [4]. The findings highlighting the importance of dealing with previously not much emphasized challenges such as "Non-technical issues" or "scalability" can be used by researchers to carve out new research agenda and directions for VM research efforts. We also expect that the results from this study will encourage researchers to carry out more studies in order to determine and understand the key problems in managing variability and the socio-technical factors that can facilitate or hinder the successful technology transfer of the outcomes of the VM research to industry.

5 Limitations

Like any empirical study, this study also has certain limitations. Our study was conducted with participants having different roles in different companies' SPL initiatives. Hence, the results are limited to the respondents' knowledge and beliefs about the challenges and issues involved in VM throughout the SPLE lifecycle. This situation

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used for this study. Despite the data analysis efforts were led by two different researchers for [2] (i.e., the second author) and for this study (i.e., the first author), some overlaps between the findings reported in [2] and in this study, especially in the section 4 of this study, are unavoidable.

can cause problems when practitioners' perceptions may be inaccurate. However, like the researchers of many studies based on opinion data (e.g., [1, 18]), we also have full confidence in our findings because we have collected data from practitioners working in quite diverse roles and directly involved in SPL activities within their organizations. Sample size may be another issue as we had only 11 participants from 11 organizations in 3 focus group sessions. To gain a broader representation of industrial challenges of VM in SPL, more practitioners and organizations need to be included in a future study. But we hope that a reader may be able to identify the challenges and some of the discussed solutions from the literature that are transferable to his/her environment. Despite the abovementioned and potentially other limitations of this empirical study, the findings from this study are expected to provide useful information about the VM issues that are perceived to be unsolved and challenging by the participants of our study.

6 Conclusions and Future Work

Effective and efficient management of variability is vital to achieve the large-scale reuse promised by the software product line paradigm. The overall goal of our research is to investigate the contemporary industrial challenges of VM in SPL after almost 20 years of research and practice. To achieve this objective, an empirical study using focus group as the data collection method was designed and executed to explore practitioners' experience and perceptions about the VM challenges in SPL.

This research has gathered empirical evidence to update and advance the knowledge about the VM challenges faced by practitioners. The findings of the study highlighted several technical issues, i.e., handling complexity, knowledge harvest and management, extracting variability from technical artifacts, evolution of variability, variability modeling and documentation, design decisions management and enforcement, tool support, and testing of artifacts with variability. Especially, the findings of the study shed light on non-technical challenges (i.e., issues regarding people, mindset change, management support, organizational structure, and business model) faced by practitioners in their daily practice of SPL. These non-technical challenges appear to have been hardly addressed by existing VM approaches, which seem to be mainly focused on technical aspects of VM [2, 5, 7-8].

The research results presented here can help researchers to identify the areas that demand further research; especially the results revealed and highlighted several neglected areas of research (e.g., tackling various non-technical challenges). Practitioners can also benefit from the findings. For example, the practitioners who are going to adopt a software product line approach can know the variability management challenges that they need to be aware of; for practitioners who have already adopted a SPL approach, the synthesized list of challenges can help them to get an understanding on what challenges their colleagues are facing, thus they can be more knowledgeable about the neglected issues in their own organizations.

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References

[1] Ali Babar, M., Bass, L., and Gorton, I., Factors Influencing Industrial Practices of Software Architecture Evaluation: An Empirical Investigation, in Software Architectures, Components, and Applications. 2007, Springer-Verlag. pp. 90-107.
[2] Ali Babar, M., Chen, L., and Shull, F., Managing Variability in Software Product Lines, *Software, IEEE*, 2010. **27**(3): pp. 89-91, 94.
[3] Bachmann, F. and Clements, P., Variability in Software Product Lines, *Tech Report CMU/SEI-2005-TR-012*, Software Engineering Institute, Pittsburgh, USA, 2005.
[4] Bosch, J., et al., Variability Issues in Software Product Lines, in Software Product-Family Engineering (PFE01). 2002, Springer-Verlag. pp. 13-21.
[5] Cawley, C., Chen, L., and Ali Babar, M., A systematic review of the research on variability management in software product lines, *Tech Report* Lero, University of Limerick, Ireland., 2008.
[6] Chen, L. and Ali Babar, M., A Survey of Scalability Aspects of Variability Modeling Approaches, in Workshop on Scalable Modeling Techniques for Software Product Lines at SPLC'09. 2009: San Francisco, CA, USA.
[7] Chen, L., Ali Babar, M., and Ali, N., Variability Management in Software Product Lines: A Systematic Review, *Proceedings of the 13th International Software Product Line Conference*, 2009. pp.
[8] Chen, L., Ali Babar, M., and Cawley, C., A Status Report on the Evaluation of Variability Management Approaches, *Proceedings of the 13th International Conference on Evaluation and Assessment in Software Engineering*, British Computer Society, 2009. pp.
[9] Haugen, Ø. Common Variability Language Request for Proposal – CVL RFP. Last accessed on 10 March, Available from: http://www.omgwiki.org/variability/lib/exe/fetch.php?id=start&cache=cache&media=cvl-rfp-091209.pdf.
[10] Kang, K.C., et al., Feature-Oriented Domain Analysis (FODA) Feasibility Study, *Tech Report CMU/SEI-90-TR-021*, SEI, 1990.
[11] Kasunic, M., Synthesis: A reuse-based software development methodology, Process Guide, Version 1.0, *Tech Report Technical Report*, Software Productivity Consortium Services Corporation, 1992.

[12] Kishi, T. and Kang, K.-C., Scalable Modeling Techniques for Software Product Lines (SCALE2009) - Bridging the Gap between research and practice, *Proceedings of the 13th International Software Product Line Conference*, 2009. pp. 311-312

[13] Kontio, J., Lehtola, L., and Bragge, J., Using the focus group method in software engineering: obtaining practitioner and user experiences, *Proceedings of 2004 Int'l Symposium on Empirical Software Engineering*, 2004. pp. 271-280

[14] Krippendorff, K., Content Analysis: An Introduction to Its Methodology. 2nd ed. 2003, Thousand Oaks: Sage Publications, Inc.

[15] Linden, F.J.v.d., Schmid, K., and Rommes, E., Software Product Lines in Action: The Best Industrial Practice in Product Line Engineering. 2007: Springer-Verlag New York, Inc.

[16] Loesch, F. and Ploedereder, E., Optimization of Variability in Software Product Lines, *Proceedings of the 11th International Software Product Line Conference*, IEEE, 2007. pp. 151-162

[17] Medvidovic, N., Dashofy, E.M., and Taylor, R.N., Moving architectural description from under the technology lamppost, *Information and Software Technology*, 2007. **49**(1): pp. 12-31.

[18] Niazi, M., Wilson, D., and Zowghi, D., A framework for assisting the design of effective software process improvement implementation strategies, *Journal of Systems and Software*, 2005. **78**(2): pp. 204-222.

[19] Park, S., Kim, M., and Sugumaran, V., A scenario, goal and feature-oriented domain analysis approach for developing software product lines, *Industrial Management + Data Systems*, 2004. **104**(4): pp. 296-308.

[20] Pohl, K., Böckle, G., and J. van der Linden, F., Software Product Line Engineering: Foundations, Principles and Techniques. 2005: Springer-Verlag New York, Inc.

[21] Pohl, K. and Metzger, A., Software product line testing, *Commun. ACM*, 2006. **49**(12): pp. 78-81.

[22] Rabiser, R., Grünbacher, P., and Dhungana, D., Requirements for product derivation support: Results from a systematic literature review and an expert survey, *Information and Software Technology*, 2010. **52**(3): pp. 324-346.

[23] Schmid, K., Babar, M.A., Grünbacher, P., and Nonaka, M., The Second International Workshop on Management and Economics of Software Product Lines (MESPUL08), *Proceedings of the 12th International Software Product Line Conference*, 2008. pp. 386-386

[24] Seaman, C.B., Qualitative methods in empirical studies of software engineering, *Software Engineering, IEEE Transactions on*, 1999. **25**(4): pp. 557-572.

[25] Sinnema, M., Deelstra, S., Nijhuis, J., and Bosch, J., COVAMOF: A Framework for Modeling Variability in Software Product Families, in Software Product Lines (SPLC04). 2004, Springer-Verlag Berlin. pp. 197-213.

[26] Strauss, A.C. and Corbin, J., Basics of Qualitative Research: Grounded Theory Procedures and Techniques. 2nd ed. 1990: Sage Publications, Inc.

[27] van Deursen, A., de Jonge, M., and Kuipers, T., Feature-Based Product Line Instantiation Using Source-Level Packages in Software Product Lines (SPLC02). 2002, Springer Berlin / Heidelberg. pp. 19-30.

[28] Ye, H. and Liu, H., Approach to modelling feature variability and dependencies in software product lines, *Software, IEE Proceedings* -, 2005. **152**(3): pp. 101-109.