Evidence from Risk Management in Software Product Lines development: A Cross-Case Analysis

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Abstract—Software Product Line Engineering is a paradigm in software development that enables rapid development of new applications, by means of systematically reusing the assets. In order to take effect and deliver the promised benefits, it demands for substantial upfront investments, and also manageable processes. Such a scenario leads to the need of a rigorous risk management, to be employed with the aim of decreasing the impact of problems that may occur during the projects' development, thus improving the use of resources. This work presents an analysis of two case studies of Risk Management practices in Software Product Line projects, carried out in academic and industry settings. In order to synthesize evidence and increase validity of the results, the outcomes were compared by means of a cross-case analysis, in which we analyzed the identified risks, their assessment and the activities used to mitigate them. The results were mapped in order to highlight the insights in both studies.

Keywords: Software Engineering; Software Product Lines; Risk Management; Cross-Case Analysis; Case Study

I. INTRODUCTION

SPL (Software Product Line) is a software development paradigm focused on systematic and large-scale software reuse. It is proved to be a paradigm that provides companies with benefits in terms of time-to-market, quality and effort. It fosters the systematic exploration of commonalities between software products [1]. Given that the SPL paradigm demands for major investments, especially in its initial development stages, risks should be managed to prevent companies from the consequences of potential negative events, which might occur during project development.

In general, most empirical evidence available in the literature about SPL refers to technical issues [2]. However, only handling technical issues might not guarantee the success of a SPL project, there are other important issues to be considered, such as Risk Management (RM) [3].

In order to contribute to the SPL field, this work presents evidence on RM practices gathered from two case studies performed in SPL projects, carried out in academic [4] and industry settings [5]. According to Yin [6], data analysis can be used to investigate evidence in a specific context, and to identify initial propositions based on previous studies. As a matter of fact, the strategy of analyzing evidence enables researchers to make data synthesis and inferences, and also to provide practitioners with recommendations on the field under investigation [7].

The objective of the analysis was to document the use of RM in SPL projects, herein presented as cases studies, and then establish the insights identified with the comparison of these studies. Thus, it is possible to build a body of knowledge about what is necessary to apply RM principles in SPL projects, and which are the main risks that can occur in an SPL project.

In order to analyze the collected data, we applied the cross-case method [8]. Such a method enables the systematic comparison of multiple case studies. According to Mills et al. [7], “while a single case study emphasizes close inspection and description of one case, the cross-case is used to reinforce validity, support generalizability, and promote theoretical elaboration”.

Eisenhardt [9] recommends useful strategies for cross-case analysis, based on data analysis. One of the strategies, applied in our investigation, is to compare pairs of cases to determine variations and similarities within each study. Another is that, if a study involves multiple case studies, it is necessary to analyze the data within a case and across (set of) cases. The former consists of a detailed analysis of each case separately, and the latter is related to a comprehensive cross-case analysis among the studies.

We believe the cross-case method is flexible enough to accommodate all of the existing different variations in the different studies, presenting the results in a concise way. We identified common and different issues between the studies to analyze the evidence and report the results. From emerging results, a number of generalizations were defined, regarding the specific ways to be followed for applying RM in SPL projects. It aims to contribute to a better understanding of the challenges and advantages found with the combination of RM and SPL, and draw conclusions about what should be done towards managing risks in SPL projects.

In the case studies, we analyzed the behavior of the RM practices during the scope and requirement disciplines, since we assume that risks are to be managed from the very initial development stages. In these disciplines, risks were managed, some activities and practices were applied to mitigate them, and the behavior of the risks were monitored and examined, having a risk assumed different likelihood and impact in different phases of the project.
The rest of this paper is structured as follows. Section 2 presents the related work. Section 3 presents an overview of the cross-case method. Section 4 describes the case studies context. Section 5 discusses the data analysis and interpretation. Outcomes from each case study are discussed in Section 6. Section 7 presents the findings from the cross-case analysis. Threats of validity are described in Section 8. Finally, Section 9 concludes the work and details future directions.

II. RELATED WORK

Although research in the SPL field has gained more attention in recent years, this same scenario does not hold true for RM in SPL. The available research in this field is very limited, since there are few investigations on RM practices for SPL [3].

This section sketches some studies found in the literature that also use the cross-case analysis, following the idea of combining evidence from multiple case studies. They demonstrate the feasibility of using such a strategy for comparing studies in Software Engineering. There are a considerable number of studies performing comparisons of multiple case studies, although studies specifically describing practices of RM in SPL are not found.

Orlikowski [10] reported on a study based on cross-case analysis, where a support case tool was proposed. The work consisted of two case studies, which data from the first were collected and coded. The second was collected and an attempt was made to use the same set of codes to analyze it. As the analysis encompassed two studies, some codes were inappropriate or inadequate to be used in both, so new or modified codes resulted from the analysis in order to present the mapping between these two studies. These were then taken back to the first case, whose data was re-sorted and re-analyzed to incorporate the new concepts.

Freimut et al. [11] compared three case studies to generalize the results. All these studies had as focus the investigation and analysis of the Riskit method – a method used to assess risks in software projects. In the first case study, performed in the year 1996 at NASA, the authors presented an exploratory study for Riskit and also compared it with a different method. The second study, conducted in the year 1998, at Nokia and DaimlerChrysler companies, was focused on the evaluation of the feasibility and usefulness of Riskit, and identified issues related to RM introduction to the project. Finally, the third study emphasized the importance of the stakeholders, as defined in Riskit, a fact that was also reported in the second study.

Shull et al. [12] used the cross-case analysis to document the integration process by building an abstraction or model of the process that was flexible enough to accommodate all of the different variations from different projects. A team of researchers carried out this model-building exercise iteratively. Finally, one single model was built that encompassed the models for the different projects.

Pernstål et al. [13] presented an empirical study about the transition of the automotive industry from mechanical to automotive software engineering. They presented a multiple case study performed based on a qualitative approach. In order to obtain validity of the results, the authors performed a within-case analysis and cross-case analysis. They observed 18 issues emerged from the obtained data, concluding that there are challenges in the research area. The majority of the findings were identified from data sources from both cases, which indicated a possibility to generalize the results to the automotive domain.

III. THE CROSS-CASE METHOD

The cross-case is a method used to investigate multiple cases studies in order to analyze them in a search for empirical evidence on a specific fact. It is specially applied to case studies that consist of multiple-case design and embedded case [6]. The cross-case analysis enables the researcher to explore the data in different ways, leading to a more well-structured, diversified and systematic analysis, which enables taking a look beyond the initial insights to develop concrete findings based on them. It is possible to synthesize the data, draw inferences, and provide recommendations [9].

The evidence is knowledge obtained from findings derived from the analysis of data and can vary in terms of strength depending on their sources. However, the evidence can be weakened by the possibility of other explanations for the results or due to weaknesses in the methods [14].

Glaser and Strauss [15] provided five reasons for the use of comparisons across cases: to ensure evidence accuracy, to establish the generality of a fact, to clarify the relevant particulars of a case, test some theory, and generate theory (or establish some definitions that should be followed). According to Pernstål et al. [13], the main rationale to choose a design based on cross-case is that it allows the enhancement of possibilities to generalize the findings from the single case study through the cross-case comparison. Yin [6] and Robson [16] emphasize that if similar results are found in both analyzed studies, the findings can be considered robust. In addition, the cross-case method enables both an in-depth analysis of each case study and the ability to elicit variables that differentiate each case from the other.

In addition, once data has been identified and the concepts applied, we followed four steps in the comparative process of the studies [15], as follows. Initially, the incidents are compared based on the category identified. Secondly, the concepts and their properties are integrated. Thirdly, the findings are delimited; in this stage, the patterns of relationships within the categories should be identified since they become apparent. Finally, the results are proposed and written.

Thus, we could explore instances of a common or similar phenomenon that occurred during the case studies. Quantitative and qualitative analysis were performed since we presented, for example, the amount of risks that occurred and analyzed the relevance of them to the project.

Despite the advantages presented with the use of cross-case, developing a good analysis and synthesis, to follow this method is not a simple matter. Eisenhardt [9] relates that the key to a good cross-case comparison among the studies is counteracting the tendencies by looking at the data in different ways, searching for patterns during the analysis. Pernstål et al. [13] highlighted that the search for patterns to the research case
is relevant, since it enhances the external validity of the conclusions drawn from each case.

In the cross-case literature, three tactics are suggested to cross-case analysis in order to avoid precipitating and even reaching at false conclusions [9]. In this paper we employed the tactic focused on selecting pairs of cases to the analysis, looking for similarities and differences among each pair. As a result, new categories and concepts can be identified about the fields in study, which the investigators had not foreseen. Thus, we identified the similarities and differences among the cases studies, with some influences from the third one, where the data were analyzed separately, as qualitative and quantitative data from each study were analyzed according to their features.

IV. CASE STUDY CONTEXT

Risk Management is necessary during the development of SPL projects, since it adds value to the project, by providing software development managers with key concepts that should be followed in order to help achieving the project success [3]. As a way to provide findings to these areas and perform RM practices in SPL projects, we performed two case studies, which are described next.

A. SPL Chair

Initially, we designed an exploratory case study on the implementation of RM in a SPL academic project, where insights were collected through a study about what may be the consequences – positive or negative – when RM practices are applied in SPL projects [4]. A number of M.Sc. and Ph.D. students, members of the RiSE Labs, which conduct their researches in the field of SPL, performed this project. The project was called RiSE Chair SPL Project (or simply SPL-Chair). Its domain is based on a paper submission management system and it was conceived based on the analysis of commonality and variability from largely used conference management systems, such as CyberChair, EasyChair, Aptor Submission and JEMS-SBC. The products assembled from the core asset base were: i) R-Chair Plus: a complete system for papers revision and submission, which is targeted at journals and conferences. It also includes a module for event management; ii) R-Chair: targeted at papers submission in Journals and their manage-ment, simplifying the submission, revision and management procedures, and iii) Smart R-Chair: targeted at papers submission in conferences and its management. It aims to simplify the submission, revision and offer resources to manage conferences [4].

During the SPL-Chair, we identified 17 risks, which were evaluated according to their likelihood, impact, status, and relevance. Thus, this research provided different insights to the SPL field, such as: risks identified in an academic project; mitigation and contingency strategies to solve them; risks exposure; and risks dependencies, which provide a representation on the impact that a risk can influence another.

B. SPL Smart

In addition, we performed a case study in an industrial context to identify risks during the SPL project [5]. The analyzed project, named SPL-Smart, belongs to the domain of healthcare information management systems. The case study was applied in a medium sized company, herein named Company-A, where we documented the empirical evidence observed during RM execution. Four products (SmartHealth, SmartClin, SmartLab and SmartDoctor) were considered.

In the SPL-Smart project, we identified 38 risks, which were analyzed, monitored, and mitigated based on the mitigation strategies used to solve, reduce or avoid the identified risks. These risks were categorized based on a classification scheme that we defined to facilitate the RM.

The choice by the development of, at least, three products in both case studies is in line with the SPL strategy defined in [17], in which the authors state (based on reported industry experience) that, after the development of the third product, the development based on SPL is more rewarding than Single System Development (SSD).

Some identified risks in both case studies are not particular to SPL; however, their impact can increase due to the inherent complexity of the SPL. Moreover, some of these risks were identified in both projects, which show that the risks are not specific for the type of the project, either academic or industrial, and they should be considered during the application of RM. In the next section, we present the analysis and interpretation of the results describing the activities that were followed to apply RM during the SPL projects execution.

The cooperation was attractive for both partners: Company-A had no research department that could tailor an SPL approach to the company specific goals, and RiSE Labs would have a validation partner for new approaches being developed. RiSE Labs conducted the technology transfer of SPL engineering for Company-A. It involved the integration of the RiSE Labs team with the Company-A staff in order to introduce SPL within the existing systems.

V. ANALYSIS AND INTERPRETATION

The project was developed following the RiPLE, which covers the whole SPL development lifecycle. In this paper, the focus was on the use of the processes for scoping and requirements, henceforth named as disciplines. Firstly, the RiPLE-SC (scoping), which is mainly responsible for analyzing whether it is worth to create an SPL based on specific scenario/goals; and next, the RiPLE-RE (requirements), which is focused on defining and managing requirement-related artifacts [3].

The individual analysis of the case studies was necessary given that the goal was to capture insights of RM practices in SPL. After the individual analysis of each study, the cross-case analysis was performed to seek a chain of evidence from both case studies, and identify the main findings.

This work was intended to compare the case studies to verify the identified risks, the severity addressed to each, as well as the activities to apply RM during the projects. In order to map the findings and identify the similarities and differences, we used tables, which according to Yin [6], is a good means to provide the foundation for the analysis and consolidation of data.

1 http:// labs.rise.com.br/
A. The Risk Management process

In both case studies, we followed pre-defined RM activities. The activities are practices to be performed aiming at data collection and analysis, and to propose improvements to the project. These were based on Boehm [18] and Sommerville [19], and were adapted according to the SPL needs. The basic activities of RM are: **Risk identification**: risks are identified during the SPL execution; **Risk documentation**: risks are documented to support their further assessment; **Risk analysis**: responsible for assessing the likelihood and consequences of risks; **Risk planning**: addressed the identified risks, either by avoiding or minimizing their effects in the project; and, **Risk monitoring**: risks are regularly assessed and mitigation plans were revised as more information about the risks became available.

These RM activities were performed in a similar way in both case studies, since the same participants worked in both projects, and the Risk Manager was also the same person (the first author of this paper). The strength of this approach is that we could really compare two cases that were performed following the same way, and to the same SPL disciplines – scoping and requirements.

A negative point with the use of the same settings in both projects is that we could not identify specific behaviors applying different settings. These differences can be related to different activities performed to provide RM during the SPL projects, and new risks that could have been identified, or could have assumed different likelihoods and impacts during the project. On the other hand, this can also be a positive aspect of this work, since the RM activities followed in the academic project were validated and reused in the industrial project.

We applied techniques to perform the data collection, during regular meetings with the participants of the case studies (from the RiSE team in SPL-Chair, and RiSE and Company-A teams in SPL-Smart), in the following way: we recorded audio during the meetings to analyze and identify possible risks that were not identified during the meetings, as well as to identify some needs of the project; focus group [20] was performed with the whole set of participants; interviews were applied to collect the participants’ feelings about the project; and observations were useful to recognize possible insights through the participants’ behavior.

During the SPL-Chair, it was not necessary to apply questionnaire and “think aloud” techniques to collect data, since the team involved was the same that developed the project. However, in the SPL-Smart, these techniques were required, because more people were involved in the project from RiSE and Company-A teams. In addition, the documentation available and the email list was analyzed in both case studies. A mailing list was created to each project, where the participants exchanged knowledge and discussed problems found during the project development.

Despite the ways used to identify data, it was important the presence of the risk manager during data collection, since team might not have the expected expertise on what should be considered and what was relevant to be collected during RM.

B. Participants

The RiSE members, composing a team of 9 software engineers, worked in the SPL-Chair project. They assumed different roles, such as developers, project manager and risk manager. A problem identified was that some of the participants did not have an adequate experience in real-world projects, which could hide some deficiencies that could be evident if they had more expertise, or some tasks could be reach better results.

In the SPL-Smart, RiSE members participated as well as some engineers from the Company-A. It is an important aspect for the project, since we could capture evidence about the risks from both contexts – academic and industrial. In this work, the risks are presented and mapped according to their source, related to which teams are responsible by the risk occurrence. We had 11 participants in the case study that were selected from different areas (development team, technology sector and management). During the execution of the SPL disciplines, the subjects were associated to different roles, either during scoping (risk manager, developers, architects, project manager, SPL expert, scope expert, configuration manager, customer and domain expert) or the requirements phase (requirement analyst, inspection manager, quality assurance engineer, configuration manager, domain analyst, domain expert, risk manager and project manager).

In both cases, we considered the actions of project stakeholders as the source of risks occurrence in the project, since no intervention of the company, such as internal policies or rules to be followed were considered. Thus, it was necessary that the stakeholders had responsibility with the tasks that should be performed during the project execution in order to achieve the project success.

C. Research Questions

Miles and Huberman [8] suggest that the themes under analysis should be verified across all of the cases to variable-oriented analysis. They recommend to follow some steps to analyze the evidence from studies: 1) identify the standard variables across the cases and within the themes; 2) then, the cases are written up in details and presented in a matrix, making reference to these standard variables; 3) a meta-matrix is developed through synthesis of the variables across all of the cases. Thus, it is possible to retain both the details of the individual cases and partial, and the overall explanation of a number of cases.

As stated by Pernställ [13], research questions related with the investigation of what, how and why are the ones most suitable in case studies. Thus, the main question in this study can be stated as: **Which risks were identified in the case studies, and how were they managed?**

As previously mentioned, we used the second tactic proposed by Eisenhardt [9], where the analysis was focused on grouping the data in pairs and the similarities and differences were identified in every pair. In order to conduct the analysis, the studies were compared based on two research questions, as follows: **RQ1. What are the main risks identified in both studies?** The risks are identified during the SPL project, and it is addressed which are common to both studies. **RQ2. How the...**
risks are measured during the project? This question investigates the likelihoods and impacts that the risks assumed during the projects.

VI. OUTCOMES

In order to improve the cross-case comparison validity, the analysis of the evidence were revised and refined by four researchers involved in this work, and all disagreements were solved with internal meetings. Meta-matrices were used to show the descriptive data from each case in a standard format and then these were crossed, according to the recommendation of Miles and Huberman [8].

In this section, we present the results from both case studies, which addressed the questions previously stated.

A. RQ1. What are the main risks identified in both studies?

According to Quilty and Cimméide [21], risks identification is a difficult activity for businesses, where a large amount of information is required from different sources, both internally and externally to the company. Thus, as previously presented, during the case studies we used different techniques of data collect to identify the risks.

The identified risks were classified in categories based on, mainly, in the research proposed by Sommerville [19]. Although one risk could be categorized into more than one category, in this work they were categorized in an exact category, the most suitable for it, as follows: R1- Cost risk; R2- Implementation risk; R3- Management risk; R4- Operational risk; R5- Organizational risk; R6- Schedule risk; R7- Technical risks; and R8- User risks. We used tags to represent the risks in the SPL-Chair and SPL-Smart projects: (✓) the risk occurred in the project; (✓) the risk did not occur in the project; (✓) the risk was avoided (a mitigation strategy was applied).

In Table I, we listed the risks identified in the projects. The risks in bold are those specific for SPL, which occurred in the projects due to the SPL characteristics. An important insight about the risks from SPL, is that the core assets development can present several risks since this task is what differentiate the product line and the traditional development. Thus, we can conclude that the specific activities to propose a product line are those that need to be managed, since mistakes can be done which may compromise all the SPL life cycle.

The risks are mapped according to the SPL essential activities proposed by the SEI [2], i.e., in which SPL activities the risk may relate with. The risks can be classified in Core Assets Development (CAD), Product Development (PD), and Management (M), which were defined based on the period of time where the risks were identified during the execution of the projects, and our expertise on RM for SPL. This classification enabled us to highlight in which SPL activities the risks are more likely to occur. In addition, the risks were categorized in categories, to facilitate their management.

In order to apply RM to a SPL project, the software engineer should consider the project development based on CAD, PD and Management. In CAD, the core assets are developed, which will be reused in PD in order to define the products, and Management is the activity that must be performed in the whole SPL development [2]. Risks that occur in CAD can lead to new risks to PD, since in the first the components are developed and in the second the products are created. Whether problems are incorporated in CAD, probably they will be in PD. The risks classified as Management Risks are those that can directly impact the project progress, since they can be disseminated to the whole product line, and instigate the occurrence of others. The risks were also analyzed according to their likelihood (L), impact (I) and severity (S) [S = L*I] they represent to the project. In a SPL a risk can impact in different products (the most relevant difference between SPL and single systems development).

Next, we describe the categories where the risks were classified, according to the SPL essential activities:

Category 1. Cost risks: We observed that no risk was categorized regarding Cost. During the execution of scoping and requirements disciplines in both projects, we did not consider cost-related issues. As the first project (SPL-Chair) was performed in an academic environment, without companies providing economic support, it was unfeasible to analyze cost-related issues. In the second project (SPL-Smart), although it was developed in-house, with total support of the company, we could not afford to consider cost analysis in this moment, due to the complexity in applying measurement strategies to define the costs.

Category 2. Implementation risks: Several risks classified in this category were only identified in the SPL-Smart, just one risk was only identified in the SPL-Chair, and three were identified in both projects. Some factors led to such observed scenario: the SPL-Smart project is more complex if compared with the SPL-Chair, i.e., the domain is more difficult to understand and implement; the project size is bigger, which demands for more artifacts to be developed; and there are more participants involved in the SPL-Smart, what implies in several opinions that should be considered and more risks involving the lack of commitment of these people, if compared to the SPL-Chair.

Another aspect is that the risks of this category are more present during the CAD activity. It can be justified because this category is related to implementation risks and CAD activity is where the assets are developed. The risks identified in CAD directly affect PD, since the outputs of this activity are inputs to the PD. Thus, problems found during CAD can directly impact PD since they can contribute with some delay in the product line development, resulting in new risks arising during the product derivation.

In the Implementation category, two risks can be highlighted: the “Inappropriate reuse”; which was avoided in the SPL-Chair since the SPL scope was smaller, and this was the first SPL project performed by the RiSE team. Thus, no previous artifacts were available that could be reused in the project. On the other hand, this risk occurred in the SPL-Smart, since some artifacts were not reused in an appropriate way, for example, the company stated that the reuse of the artifacts was not performed in a systematic fashion. Another risk, the “Inadequate core assets traceability” was avoided in the SPL-Smart, because during this project, we developed a tool to assist the management of the identified risks.
<table>
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<th>Categories</th>
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<th>Risk Name</th>
<th>SPL-Chair</th>
<th>SPL-Smart</th>
<th>SPL activity</th>
<th>SPL-Chair</th>
<th>SPL-Smart</th>
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<td>R2.2</td>
<td>Absence of non functional features</td>
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<td>R3.3 Inadequate configuration</td>
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<td>R5.3</td>
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<td>R5.4 Project is discontinued</td>
<td>R6.1</td>
<td>Delayed inspection rounds</td>
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<td>Delay in time-to-market</td>
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<td>R6.6</td>
<td>Tight schedule for the project</td>
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<td>R7.7 Lack of support tools</td>
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<td>Absence of domain experts</td>
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<td>R8.2 Absence of SPL experts</td>
<td>R8.3</td>
<td>Client understanding of SPL</td>
<td>2</td>
<td>3</td>
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<td>R8.4 Difficulties in</td>
<td>R8.5</td>
<td>Lack of team commitment</td>
<td>2</td>
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<td>R8.6 Not qualified staff</td>
<td>R8.7</td>
<td>Staff turnover</td>
<td>1</td>
<td>3</td>
<td>3</td>
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<td>R8.8 Working remotely</td>
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This tool was necessary to the project, since some problems identified during the SPL-Chair was due to the difficult to manage the artifacts and provide traceability among them.

A recurrent observation among the risks in this category, for both case studies, is that the specification of correct measures about the artifacts development is not a trivial task. The development of the artifacts has to be done on a level where it is possible to interpret their impact for the design of a specific system.

**Category 3. Management risks:** This category includes risks related to project management activities. Through the cross-case analysis, it was noticed that there was a deviation between the projects regarding this category. During the SPL-Chair most risks were not identified, and, they occurred during the SPL-Smart. We can think about the possible reasons, however, the main one refers to the fact that the project management was not performed in an adequate fashion, since the risks that materialize could have been avoided if a systematic management had been performed. This is justified because during the SPL-Smart project, the risk manager had to be absent for a period, managing the project remotely.

Regarding the SPL-Smart, the same assumption for the number of risks that occurred in the Implementation risk category can be made to the Management risk category, for domain complexity. In the SPL Smart, it was required that the RiSE members had the understanding of the domain, completely new to most of the team. During the SPL-Chair, the scenario was different, since all participants had already used submission systems, hence referring to a well-known domain.

We highlight two risks in this category: the “Inadequate risk management” that was avoided in the SPL-Chair, since no problem was identified intrinsically linked with this risk. Regarding the “Inadequate training”, this risk was avoided in the SPL-Smart, since the Company-A provided trainings to the RiSE members about the project domain and their products.

**Category 4. Operational risks:** The risk “Inadequate communication” was verified in both projects. Despite the main occurrence factor of this risk is related to the M activity, it can hinder the CAD and PD activities, since the communication is essential during the whole SPL development. The participants were aware that such risk could affect the progress of the entire project and could influence the SPL management, causing mismanagement. Hence, the practice of communication was required among the stakeholders in order to avoid the negative consequences of this risk.

**Category 5. Organizational risks:** This category is related to risks that involve the organization at all. Based on the cross-case synthesis, we could observe that all risks classified in this category occurred in the SPL-Smart. In the SPL-Chair, we did not have a company mediating the project development, since the project was developed in academic settings, in a narrower scope. Thus, the “Cultural barriers” and “Project is discontinued” did not happen in this project.

It is important to consider organizational risks in the SPL development in industry settings, in order to prepare the organization to understand the SPL practices. It is also important to solve the problems that can be found with the SPL introduction as the main development paradigm, since some practices should be changed in the organization towards the SPL adoption, which can result in changes in the development and staff practices.

**Category 6. Schedule risks:** These are risks related to the time spent to perform the project, to develop artifacts, to undertake the product derivation, and to deliver the product to the market. These risks were classified as risks related to CAD and PD.

“Missed schedule” and “Delay in time-to-market” occurred each in SPL-Chair and SPL-Smart, respectively. Despite the occurrence of missed schedule, it does not mean that risk of the time-to-market will occur, since the delays can be solved before the products are delivered to the market. Others risks related to time not occurred in the academic project because the scope was smaller than the industrial project, and the schedule could be more controlled. In addition, in the industrial project, we had more participants involved and a more complex domain was chosen, which resulted in a delay to finish the activities, and, consequently, in more time-related risks.

**Category 7. Technical risks:** Risks in this category were identified in the SPL-Chair and SPL-Smart. We can highlight the “Inadequate process” risk that occurred in the academic project. However, it was avoided in the industrial project. As the processes followed to develop the product line had been validated during the SPL-Chair, all discrepancies were earlier solved. As presented in Table I, technical risks are evenly common in both CAD and PD, since they are, in general, related to the functionalities development and performance of the system.

**Category 8. User risks:** The main source to the risks occurrence is directly related to the users, which can be internal or external stakeholders involved with the project. Risks that encompass this category affect the development of the assets, as well as the instantiation of the products, leading mainly to the occurrence of risks related to schedule.

The risks categorized as User risks were more identified during the SPL-Smart. This can be related to the number of participants involved in the industrial project, and the amount of activities that were performed during the execution of the scoping and requirements disciplines, since a considerable number of activities were addressed to the users. Other factors that can influence these risks are the roles assumed by the stakeholders. In both SPL-Chair and SPL-Smart, the team responsible for the project development worked during the entire project, and the same participants assumed different roles, what may be a problem since a significant number of tasks were associated to the stakeholders.

In general, the stakeholders must know about how their actions can affect the project if they are not executed with commitment. Thus, the risks from this category are important and the risk manager should select users that have knowledge with the project and commitment with the work.

**B. RQ2. How are the risks measured during the project?**

After the identification of the risks in the projects, we analyzed them to identify their severity, and them to plan the proper mitigation and contingency strategies. This question is
related to the cross analysis of the likelihood and impact that the risks assumed in the projects. In order to control the interferences of the risks for the project, the risks were periodically monitored and assessed. In this work, we addressed the assessment in a superficial way, since the goal was to highlight the similarities and differences showed by the case studies, rather than presenting a complete view about all the insights collected during the projects execution.

As a way to summarize our findings, we presented the risks assessment, as defined in the beginning of the project. The initial analysis carried out was to define the likelihood and impact of each risk, for both SPL-Chair and SPL-Smart projects. The risk assessment results presented considerable variations among the projects, due to the dynamic nature of RM and specific characteristics of each project.

Higher severity values for risks were more evidenced in initial phases of the projects. As the risks had been identified, strategies were applied to mitigate them. RM was performed in the project and the risks were treated, and lessons learned were also collected, as strategies to avoid that some risks became real, or even to avoid a next occurrence of already experienced risks. Thus, after the first analysis on the risks severity, the damages associated with them could be decreased or solved. This analysis is an attempt to quantify the risks based on what can be a quite problem to the project. In this way, the severity is relevant in order to highlight the risks that can cause more damage to the projects.

Next, we describe the cross data about the risks assessment. The assessment is presented following the category, which the risks were encompassed. During the SPL-Smart, the risks that presented the same likelihood and impact of the risks from the SPL-Chair also had the same mitigation strategies to solve them. This decision was followed since the lessons learned are good practices to be applied because they were already tested and approved.

In the Implementation risks category, more risks were identified during the SPL-Smart than SPL-Chair, and the risks severity in the industrial context were more harmful to the project. This can be justified by the involvement of a company and the relevance of the project. Three risks were common among the projects, and only one risk had the equal severity in both projects, the “Core assets instability”. Despite these achievements, the risks severity can be different to each project, depending on the environments and the context where the project is performed.

In the Management risk category, only two risks were common to both projects, “Bad practices in management” and “Rework”, and one presented the same severity. As previously mentioned, the risks of this category are more critical to the SPL-Smart, since the risk manager was not present during the whole project development. Only one risk, “Inadequate communication”, was categorized in the Operational risks category, and it occurred in both projects, however in the industrial settings it presented a higher severity. As this project involved stakeholders allocated in different environment (RISE and Company-A teams), thus the communication is more difficult. The risks “Difficulties in introducing SPL” and “Infrastructure unavailability” are the most harmful risk to the Organizational risks category. Thus, the Risk Manager must carefully look to insights that can take from their occurrence.

The risk “Delayed validation of artifacts” was the most serious risk in the Schedule risks category, based on the risks severity. A possible reason is because if the validation of the artifacts is delayed, all the risks related to the schedule can occur such as “Delay in time-to-market”. This can be verified since other risks related to schedule occurred in the SPL-Smart. However, despite the occurrence of risks related to time, the “Missed schedule” risk was avoided in the SPL-Smart. The risks classified as Technical risk category had a higher severity value in the SPL-Smart. As it involved a real-world project, there was an organization involved and customers imposing their requirements. In the User risks category, the risks “Absence of domain expert” and “Lack of team commitment” had the same likelihood and impact for both projects, while the first had the higher severity. In the SPL-Smart, there were more risks that addressed the users, since we had more participants involved in the project.

The risks can be opportunities to the project, however, in this work, the risks assessment is related to the negative impact that they can cause to the good progress of the project. Thus, in order to reduce the likelihood of the risks occurrence in the projects, we used RM plans, composed of mitigation strategies, which are used to solve the risks. RM plans are defined actions that can be used to control the risks, reducing the probability or the impact of the potential problem occurrence.

Despite the use of plans with mitigation strategies, no project can avoid all kinds of risks, even if there are contingency plans for every uncertainty. However, risks can be avoided and the likelihood and impact can be reduced if there are RM plans for every situation and possible risks through the periodic evaluation of them.

VII. DISCUSSION

The main goal of this work was to highlight the findings from the case studies performed to apply RM in SPL project. The criteria for analyzing the results were based on contextual similarities rather than diversities presented by the case studies, as proposed by Pernstål et al. [13].

The lack of empirical research of RM in SPL projects motivated the nature of this study, since few results based on empirical analysis are available in the literature. In this sense, the cross-case was applied in order to facilitate the analysis of the developed case studies, based on the fact that the evidence analysis from more than one study strengthens the pattern from one data source, and so the finding is stronger and better grounded. Whether the evidence were conflicting, a deeper probe was necessary on the meaning of the differences.

Despite few data available in the literature about RM in real SPL projects [3], in the studies analyzed in this research, we could identify several risks that occurred, and strategies to avoid and solve them. The identified risks in the academic project also occurred in the industrial context, and some of them, listed in this work, are specific to the SPL complexity. Thus, the SPL experts involved in the project should aid in how to solve the risks.
Some risks, as well as the RM activities performed to manage them during the case studies can also be addressed in single system software development; however, in this work they had been identified through the SPL projects. The differences on RM to these development paradigms is that in product lines we need to consider the whole SPL to apply RM, since several changes can be proposed during the development, which may impact the whole product line. The RM must be performed during the SPL activities – PD, CAD and Management. Moreover, the management is the activity that should encompass the whole development.

We observed that the Risk Manager is a relevant role to the project success. If a problem is either avoided or solved, the project execution has more chances to follow the defined schedule and consequently achieve positive results. In addition, it is interesting that the Risk Manager assumes only the RM activities in order to avoid that overload brings problem to the management.

The RM activities applied in the case studies were essential to collect the data, thus they must be considered to apply RM during software development. These were based on studies that encompass research to RM in traditional software engineering [18].

The occurrence of one specific risk can imply the occurrence of other risks. Thus, besides the need of analysis and monitoring, it is necessary to think about traceability, which is related to the propagation that the risk occurrence may cause to the project at all. Thus, it is worth thinking about different scenarios where risks can occur and verify the traceability in order to avoid that others risks become real to the project, as follows:

- A scenario related to the risks that are intrinsically related, i.e., if a risk occurs, it is certain that other risks will be present in the project as well. As this situation is expected, the impact of the second risk can be reduced, since the contingency strategies are planned. Thus, these types of risks cannot bring serious consequences to the project if they have been anticipated.
- A scenario is related to risks that present a low perspective of occurring together, i.e., a low likely-hood. However, if it occurs, they cause a devastating knock-on effect to the project, i.e., a high impact.
- Another scenario is related to the risk that has high likelihood to occur and their occurrence presents low impact to the project, leading to risks with low impact too. Due to the high likelihood to occurrence, these risks can be previously avoided, however, it is important to analyze the time spend with this resolution in order to know which is more worthwhile.

Based on the possible situations related to the impact of a risk on each other, we argue about the relevance in defining the risks dependences. As example, we can cite, the analysis of the risk R3.1 – Bad practices in management and its dependences, which impact several other risks from the project. Despite the risk presented low likelihood to the project, their impact is high since other risks may occur together with its occurrence.

Another relevant risk is the R8.2 – Absence of SPL experts, which causes the occurrence of several other risks, since if these experts are not present this can cause risks specific of SPL and related to development risks.

The dependences among the risks may be relevant to the manager, since it can be seen whenever a specific risk occurs in the projects. Thus, it is possible to know which are the potential risks that can occur in the software development.

VIII. THREATS TO VALIDITY

In this section, we present the threats to the validity of this study. Some of them were based on recommendations proposed by other authors and were adapted to our context. Yin [6] presents four main types to evaluate the validity, which can be applied in this study, as follows:

**Construct validity:** the threats here can be concerned with the researcher biases. In order to mitigate this threat, four strategies can be used [16]: Prolonged involvement, means learning the culture and to build trust. In order to avoid stakeholders’ bias, all the participants of this work have worked at least 3 years with SPL; Triangulation comprises the use of multiple sources that enhance the rigor of the research. The embedded multiple design used in this work (since the case studies encompassed two analysis units – scoping and requirements SPL disciplines) enables the possibility to triangulate different sources of evidence, as provided by interviews, documentation analysis, observations, and so; and Peer debriefing, means that analyzes and conclusions are shared and reviewed by other researchers. In this work, four researchers conducted the analysis between the case studies and discussions were realized in order to avoid all the disagreements.

It is possible that not all findings have been identified and represented with the use of the cross-case study. This has impact on the results related to the validity and generalizability of the findings.

**Internal validity:** this is related to establish causal relationships, whereby certain conditions are shown to lead to other ones. In our study, the threat can be related to that the same team member developed the two case studies, and the researchers that conducted the evidence analysis were the same that reported the results in the cases. Thus, it can be that the researchers impose some biases. However, according to Yin [6], internal validity is mainly related to explanatory studies, and this study is explorative.

**External validity:** this refers to the definition of the domain in order to generalize the study findings. The multiple case study design enhances the possibility to generalize the results to other SPL projects where RM is performed. Despite such a statement, similar studies from different projects may result in other findings since RM depends on the Risk Manager perception. The concern for validity may occur if the number of cases increases and so, the amount of data collected increase as well. In this work, this was solved, since we limited the analysis in two case studies.

**Reliability:** this refers to the possibility that whether a researcher follows the same procedures performed in this work,
the same findings and conclusions should be obtained to the case studies analyzed.

It is impossible to know if all the relevant cases were identified as evidence. Thus, we do not know if the amount of evidence is sufficient to support the researcher’s claims.

IX. CONCLUSIONS

In this work, we examined in details the findings from the cases studies on RM in two SPL projects. It analyzed the context and characteristics of them, identifying the similarities and differences in order to provide a concise set of results. Then, for each study, the notes were used to build preliminary results about the insight on RM. Finally, the results obtained through the cross-case were mapped and presented.

The similarities points out to evidence that can be common in other studies that manage risks during SPL projects, thus, these evidence enhance the possibility to generalize the findings to this field. Moreover, through the differences, we could observe issues that can be specific to the project in development. These should be carefully analyzed, since, for example, the identified risk can have occurred due to decisions or actions defined by project team much more then related to the development paradigm used.

As future work, we intend to perform other case studies in different domains. It will be important to improve the evidence on RM to SPL, since other activities can be required, and new findings can be captured. Moreover, based on the findings identified, we are defining a new approach for RM in Software Product Lines.

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