Towards the Effectiveness of a Variability Management Approach at Use Case Level

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***Abstract*—Software product line (PL) is an approach focused on a systematic software reuse that has been successfully applied to specific domains. One of its essential activities is the variability management to which there are several existing approaches, including the UML-based SMarty approach. Although there are several variability management approaches for PL, there is a need to demonstrate the effectiveness of such approaches for industry adoption. Therefore, this paper presents an experimental study that aims to gathering evidence of the SMarty approach effectiveness at use case level taking into consideration a consolidated and well-known UML-based variability management method, named PLUS. The experimental study provided evidence that SMarty is an effective approach for managing variability at use case level.**

I. Introduction

The software product line (PL) approach has gained increasing attention in recent years due to the competition in the software development segment [1]. Its main objective is the derivation of products for a specific domain. Such an approach comprises a set of essential activities, such as variability management, which is a key issue for the success of PLs. Several approaches for variability management have been proposed in the literature, as pointed out by Chen et al. [2].

Amongst existing variability management approaches are SMarty [3] and the PLUS method [4]. SMarty aims to manage variabilities in UML models supported by a profile and a set of guidelines for applying such a profile to use cases, classes, components, activities, and sequence models, as well as to packages. PLUS is a well-known method that allows explicit modeling of common and variable features supported by UML extensions for use case and class models.

These approaches are promising taking into consideration the variability management research field. However, their effectiveness was not experimentally analyzed, which can make it feasible for technology transfer to industry. Therefore, this paper presents an experimental study to gathering initial evidence with regard to the effectiveness of the SMarty approach by targeting UML use case models for a given PL. Use case models play an essential role in PL by linking features to lower-level models of a PL archicteture, such as classes and components, taking into account important traceability issues. The following use case relationships are taking into consideration: communication, include, extend, and dependency [3].

The remainder of this paper is organized as follows: Section II presents essential concepts with regard to variability management, the SMarty approach and the PLUS method; Section III presents the planning, execution and analysis and interpretation of this experimental study; and Section IV presents conclusion and directions for future work.

II. Background

A. Variability Management

Variability management is an essential PL activity for the derivation of specific products for a given domain. It brings out important benefits, such as, increases the reusability of the PL core assets, while decreases the time to market and justify the return on investment (ROI).

There are four main concepts taking into consideration for variability management, which are:

- **Variability**, according to Pohl et al. [1], is "the ability of a software or artifact to be changed, customized or configured for use in a particular context."
- **Variation Point** is the resolution of variabilities in generic artifacts of a PL. According to Jacobson et al. [5], "a variation point identifies one or more locations at which the variation will occur." Basically, a variation point answers the question: What varies in a PL? [1].
- **Variant** represents the possible elements through which a variation point may be resolved. Basically, a variant answers the question: How does a variability or a variation point vary in a PL? [1].
- **Variant Constraints** state the relationships between two or more variants to resolve a variation point or a variability. For instance, a PL manager decides not to offer certain combinations of mutually exclusive variants for a set of products. Thus, a mutually exclusive constraint needs to be defined for these variants.

The relevance of the variability management activity for PLs has been gained attention of many researches, as we can see in several existing studies in the literature [2], [4], [6]–[8].

Several existing variability management approaches do not make it clear how to identify, represent and trace variabilities in different artifacts [2], specially those based on UML models. This kind of approach most takes into account stereotypes and tagged values for representing PL variabilities. However, they fail on presenting the rationale on how to apply such stereotypes and their relationships. Industry needs evidence on the effectiveness of these approaches to make their adoption feasible.

In order to provide a more precise UML-based approach for variability management, we have been developed the SMarty approach [3], [9], which is supported by a profile and a set of guidelines for applying its stereotypes and relationships. However, we need to gathering initial evidence with regard to its effectiveness by means of an experimental study. Therefore, the Gomaa's widely-known PLUS method [4] was chosen to perform such an experimental study. Thus, next sections present the PLUS method and the SMarty approach essential concepts.

B. The PLUS Method

The *Product Line UML-based Software Engineering* (PLUS) method, proposed by Gomaa [4], allows its integration with other software process models, such as, the unified process (UP) development.

Gomaa proposes several PL activities for requirement, analysis and design. The requirement activity encompasses PL scope definition, use case modeling and feature modeling. The analysis activity is composed by: static modeling, object construction, dynamic modeling, finite state machine and feature/class dependency modeling.

The PLUS use case modeling activity aims to explicitly model commonalities and variabilities. PLUS provides a set of concepts and techniques to extend UML-based design methods and processes for single systems to handle PLs.

PLUS does not provide a definition of an UML profile, thus there is no explicit meta attributes and classes for the variability modeling activity. PLUS uses stereotypes to provide identification of variation points and variants, in which several of them are specific to certain UML models. The rationale with regard to the use of such stereotypes is twofold: forward evolutionary engineering and reverse evolutionary engineering.

The stereotypes proposed by the PLUS method to represent variabilities in use cases are as follows:

- ≪kernel≫ - used to represent a mandatory use case, which is always selected for PL specific products;
- ≪optional≫ - used to represent use cases that might be present in a PL specific product;
- ≪alternative≫ - used to represent a mutually exclusive relationship between use cases.

PLUS is a well-known method, thus this is the main reason for its selection for this study, as it can be observed in the studies of Bragança and Machado [6], Gomaa [4], Korherr and List [7], Ziadi et al. [8], and Chen et al. [2].

C. The SMarty Approach

SMarty [3] is an approach for UML **S**tereotype-based **M**anagement of V**ar**iabili**ty** in PL. It is composed of an UML 2 profile, the *SMartyProfile*, and a process, the *SMartyProcess*.

SMartyProfile contains a set of stereotypes and tagged values to represent variability in PL models. Basically, *SMartyProfile* uses a standard object-oriented notation and its profiling mechanism [10] both to provide an extension of UML and to allow graphical representation of variability concepts. Thus, there is no need to change the system design structure to comply with the PL approach.

SMartyProcess is a systematic process that guides the user through the identification, delimitation, representation, and tracing of variabilities in PL models. It is supported by a set of application guidelines as well as by the *SMartyProfile* to represent variabilities.

The **SMartyProfile** comprises the following stereotypes, which can be applied to UML use case, class, component, activity, and sequence models, as well as it supports the package merging UML mechanism:

- ≪**variability**≫ represents the concept of PL variability and is an extension of the metaclass `Comment`;
- ≪***variant***≫ represents the concept of PL variant and is an abstract extension of the metaclasses `Actor`, `UseCase`, `Interface`, and `Class`. This stereotype is specialized in four other non-abstract stereotypes which are: ≪mandatory≫, ≪optional≫, ≪alternative_OR≫, and ≪alternative_XOR≫.
- ≪**mandatory**≫ represents a compulsory variant that is part of every PL product;
- ≪**optional**≫ represents a variant that might be selected to resolve a variation point or a variability;
- ≪**alternative_OR**≫ represents a variant that is part of a group of alternative inclusive variants. Different combinations of this kind of variants may resolve variation points or variabilities in different ways;
- ≪**alternative_XOR**≫ represents a variant that is part of a group of alternative exclusive variants. This means that only one variant of the group can be selected to resolve a variation point or variability;
- ≪**mutex**≫ represents the concept of PL variant constraint and is a mutually exclusive relationship between two variants. This means that when a variant is selected another variant must not be selected; and
- ≪**requires**≫ represents the concept of PL variant and is a relationship between two variants in which the selected variant requires the presence of another specific variant.

III. The Experimental Study

This study is characterized as a quasi-experiment [11] that relaxes the conditions imposed by probability distributions and statistical inferences for the population. Therefore, we performed the non-equivalent grouping method, considering that the population distribution was not random (discussed in Section III-E).

A. Definition

The goal of the experiment was to **compare** the PLUS method and the *SMarty* approach, **for the purpose of** identify the most effectiveness, **with respect to** the capability of identification and representation of variabilities in Software Product Line use case models, **from the point of view of** software product line architects, **in the context of** graduate students and lecturers of the Software Engineering area from the State University of Maringá (UEM), Federal Technological University of Paraná (UTFPR), and Federal University of Amazonas (UFAM).

B. Planning

1) **Local Context:** a PL for Electronic Commerce (e-commerce), proposed by Gomaa [4], was taken into consideration to apply the PLUS method and the SMarty approach aiming the representation of variabilities in use case models.
2) **Training:** subjects were trained with regard to essential concepts of PL and variability and use case model variability identification and representation using PLUS or SMarty.
3) **Pilot Project:** a pilot project was performed for evaluating the study instrumentation taking into account a small sample of graduate students and a lecturer of software engineering. Thus, corrections on the instrumentation were made based on the pilot project results. Note that the pilot data was not taken into consideration by the overall experimental study data analysis.
4) **Selection of Subjects:** the subjects must be graduate students, lecturers or practitioners of the software engineering area with at least minimal knowledge in modeling use cases. In addition, after the training sessions, each subject must be familiar with the essential variability management concepts (Section II-A).
5) **Instrumentation:** every subject was giving the following documents:
   - the consent form to the experimental study;
   - a characterization questionnaire, in which the subjects must indicate their academic background, area of expertise and experience, their level of experience with the UML notation and the PL approach; and
   - the description of the e-commerce PL and its use case model with no variabilities represented.

   Subjects were splitted into two groups. One group focused on the X approach (the PLUS method) and one group focused on the Y approach (the SMarty approach). One group was trained to identify and represent variabilities according to the X approach. The other group was trained to identify and represent variabilities according to the Y approach.
6) **Hypothesis Formulation:** the following hypothesis were tested in this study:
   - **Null Hypothesis** (H_0): both X and Y approaches are equally effective in terms of representing variabilities in use case models.
     $H_0 : \mu(\textit{effectiveness(X)}) = \mu(\textit{effectiveness(Y)})$;
   - **Alternative Hypothesis** (H_1): X approach is less effective than Y approach.
     $H_1 : \mu(\textit{effectiveness(X)}) < \mu(\textit{effectiveness(Y)})$; and
   - **Alternative Hypothesis** (H_2): X approach is more effective than Y approach.
     $H_2 : \mu(\textit{effectiveness(X)}) > \mu(\textit{effectiveness(Y)})$.
7) **Dependent Variables:** the effectiveness calculated for each variability management approach (X and Y) as follows:
   $$\textit{effectiveness(z)} = \begin{cases} nVarC, & \text{if } nVarI = 0 \\ nVarC - nVarI, & \text{if } nVarI > 0 \end{cases}$$
   where:
   - z is the variability management approach
   - *nVarC* is the number of correct identified variabilities according to the z approach
   - *nVarI* is the number of incorrect identified variabilities according to the z approach
8) **Independent Variables:** the variability management approach, which is a factor with two treatments (X and Y) and the e-commerce PL, which is a variable with a prefixed value.
9) **Qualitative Analysis:** aims to evaluate the results obtained in this study with respect to the results obtained by means of descriptive statistical analysis, based on the effectiveness obtained from the resolution of the use case variability model by each subject, according to the X and Y approaches.
10) **Random Capacity:** the selection of the subjects was not random within the universe of the volunteers as this was quite restricted. The random capacity took place at the assignment of the variability management approach (X or Y) to each subject.
11) **Block Classification:** because the application of two different approaches to represent variability in use case models, it was performed the random sampling, where the population was divided into two blocks, one for the X approach and one for the Y approach.
12) **Balancing:** tasks were assigned in equal numbers to a similar number of subjects.
13) **Review Mechanism:** for reviewing the study analysis it was used the calculation of the effectiveness for each treatment.

C. Execution

1) **Selection of Subjects:** it was selected for this study 21 graduate students and 3 lecturers of the Software Engineering area.
2) **Instrumentation:** the main assessment tool was the e-commerce use case model with variabilities represented according to the X and Y approaches. The main task for each subject was reading and understanding the e-commerce PL overview. Then, the subjects annotated variabilities in the e-commerce use case model.
3) **Participation procedure:** standard procedures were adopted for each subject participation, which are:
   a) the subject attends the place where the study was conducted;
   b) the experimenter gives the subject a set of documents:
      - the experimental study consent form;
      - the characterization questionnaire;

- essential concepts on variability management in PL; and
- the description of the e-commerce PL.

c) the subject reads each given document;
d) the experimenter explains the given documents;
e) the experimenter randomly associates each subject to the X or Y approach;
f) the experimenter trains the subjects on the respective approach;
g) the subject reads and clarifies possible doubts about his/her assigned approach; and
h) the subject identifies and represents variabilities in the e-commerce use case model according to his/her given approach.

4) **Execution:** collected data is presented in Table I and analyzed using appropriate statistical methods, which are properly discussed in Section III-D. For each subject (“`Subject #`” column), it was collected the following data for his/her given approach: the number of correct and incorrect identified and represented variabilities; and the effectiveness calculation.

D. Analysis and Interpretation

Based on the results obtained by analyzing the application of the PLUS and SMarty to the e-commerce PL, the following steps were taken:

- analyze and interpret the X and Y collected data (sample) by means of the Shapiro-Wilk normality test and the T-test; and
- analyze and interpret the correlation between the effectiveness of the approaches and the subjects characterization questionnaire by means of Shapiro-Wilk normality tests and the Spearman’s ranking correlation technique.

1) Effectiveness of the Approaches:

- **Collected Data Normality Tests:** the Shapiro-Wilk [12] normality test was applied to the e-commerce sample (Table I) providing the following results:
  - for the X approach with sample (SampleX) size (N) 12, mean value (μ) 1.6667, standard deviation value (σ) 4.1096, it was obtained *p* = 0.0827, which means that with α = 0.05, the sample is normal;
  - for the Y approach with sample (SampleY) size (N) 12, mean value (μ) 4.500, standard deviation value (σ) 5.5453, it was obtained *p* = 0.1378, which means that with α = 0.05, the sample is normal.
- **T-Test for SampleX and SampleY:** this kind of test can be applied for both independent and paired samples. In the case of this study, SampleX and SampleY are independent. As each sample size is less than 30 and both samples are normal, it was defined the following hypothesis:
  - **Null Hypothesis** (H_0): approach X has the same effectiveness of approach Y.
    H_0 : μ(*effectiveness(X)*) - μ(*effectiveness(Y)*) = 0;
  - **Alternative Hypothesis** (H_1): approach Y is more effective than approach X.
    H_1 : μ(*effectiveness(Y)*) - μ(*effectiveness(X)*) $>$ 0.

First we obtained the value of *T*, which allows the identification of the range entered in the statistical table t (*student*). This value is calculated using the average of SampleY ($\mu1$ = 4.5000) and SampleX ($\mu2$ = 1.6667), standard deviation value of both ($\sigma1$ = 5.5453 and $\sigma2$ = 4.1096), and the sample sizes (*N* = 12). It was obtained the value *t* = 3,9699.

By taking the sample size (*N* = 12), we obteined the degree of freedom (*df*), which combined to the t value indicates which value of *p* in the t table must be selected. The *p* value is used to accept or reject the T-test null hypothesis (H_0).

By searching the index *df* and defining the value *t* at the t table (*student*), we found a value which is greater than 0.001, with a significance level (α) of 0.05. The relation between α and *p* produces *p* = 0.001, which is less than α = 0.05. Therefore, the null hypothesis H_0 must be rejected and (H_1) must be accepted. It means that there is evidence that the Y approach (SMarty) is more effective in identifying and representing variability in use case models than the X approach (PLUS). This result also corroborates to reject the null hypothesis (H_0) of this experimental study (Section III-B) and accept the alternative hypothesis (H_1).

2) Correlation between the Approaches Effectiveness and the Subjects Variability Characterization:

- **Subjects Variability Characterization Normality Test:** Shapiro-Wilk was applied to the data extracted from the subjects characterization questionnaire of each approach:
  - for the X approach with sample size(*N*) 12, mean value of (μ) 2.2500, standard deviation value of (σ) 0.9242, the calculated variability knowledge level was *p* = 0.0002. This value with α = 0.05, indicates that the characterization data is normal;
  - for the Y approach with sample size(*N*) 12, mean value of (μ) 2.9167, standard deviation value of (σ) 1.1149, the calculated variability knowledge level was *p* = 0.4333. This value with α = 0.05, indicates that the characterization data is non-normal;
- **Spearman’s Correlation:** this technique was applied to verify whether there is a correlation between the effectiveness of each approach (X and Y) and the level of knowledge of the subjects. Equation 1 shows the formula to calculate the Spearman ρ correlation, where *n* is the sample size:

$$\rho = \{1 - \frac{6}{n(n^2-1)} \sum_{i=1}^{n} d_i^2 \qquad (1)$$

TABLE I
E-COMMERCE PL COLLECTED DATA AND DESCRIPTIVE STATISTICS: X (PLUS) AND Y (SMARTY) APPROACHES.

The X Approach (PLUS)			
Subject #	Correct Identified Variabilities	Incorrect Identified Variabilities	Effectiveness Calculation
1	5	6	-1.0
2	8	3	5.00
3	9	2	7.00
4	6	5	1.00
5	8	3	5.00
6	10	1	9.00
7	5	6	-1.00
8	4	7	-3.00
9	4	7	-3.00
10	8	3	5.00
11	4	7	-3.00
12	5	6	-1.00
Mean	6.3333	4.6667	1.6667
Std. Dev.	2.0548	2.0548	4.1096
Median	5.5000	5.5000	0.0000

The Y Approach (SMarty)			
Subject #	Correct Identified Variabilities	Incorrect Identified Variabilities	Effectiveness Calculation
1	5	6	-1.00
2	10	1	11.00
3	5	6	-1.00
4	8	3	5.00
5	11	0	11.00
6	11	0	11.00
7	9	2	7.00
8	9	2	7.00
9	5	6	-1.00
10	9	2	7.00
11	2	9	-7.00
12	8	3	5.00
Mean	7.6667	3.3333	4.3333
Std. Dev.	2.6874	2.6874	5.3748
Median	8.5000	2.5000	6.000

Table II presents the data needed to calculated the Spearman correlation for X and Y effectiveness and the subjects level of variability knowledge.

Equations 2 and 3 present the calculation of the Spearman correlation for the X (Corr.1) and Y (Corr.2) approaches, respectively.

$$\left.\begin{array}{l}\rho(Corr.1) = 1 - \frac{6}{12(12^2-1)} * 112 = 1 - 0.39 = \\ 0.61\end{array}\right\} \quad (2)$$

$$\left.\begin{array}{l}\rho(Corr.2) = 1 - \frac{6}{12(12^2-1)} * 300 = 1 - 1.04 = \\ -0.04\end{array}\right\} \quad (3)$$

Corr.1 for the X approach shown that there was a positive strong correlation ($\rho = 0.61$). This means that the subjects knowledge level on variability is important to correctly apply the PLUS method stereotypes for identifying and representing variability in use case models. On the other hand, Corr.2 shown that there was a negative weak correlation ($\rho = -0.04$). This means that the subjects knowledge level on variability is not important to correctly apply the SMarty approach stereotypes for identifying and representing variability in use case models.

An important evidence of this analysis is that the PLUS method does not provide guidelines to identify and represent variabilities in use case models. Thus, there is a need for previous variability knowledge to properly apply the PLUS stereotypes. In addition, the SMarty approach provides a set of guidelines, which may improve the activity of identification and representation of variabilities in use case models even for those subjects with lower variability knowledge level.

E. Validity Evaluation

1) **Threats to Conclusion Validity:** the major concern is the sample size. Although obtaining well-qualified subjects is not an easy task in software engineering experiments, we tried to minimize this threat by selecting the subjects by convenience. However, it is clear that such a sample must be increased in prospective studies to allow generalizing the conclusions.
2) **Threats to Validity Construction:** effectiveness is calculated based on the ability ot the subjects in modeling variability by taking into consideration the X and Y approaches and the e-commerce PL. The independent variable `variability modeling approach` is guaranteed by the pilot project undertaken.
3) **Threats to Internal Validity:** we dealt with the following issues:
   - **Diferences among subjects:** as we took into consideration a small sample, variations in the subject skills were reduced by performing the tasks in the same order. The subjects experience had approximately the same level for UML modeling and variability concepts;
   - **Fatigue effeects:** on average, the experiment lasted for 100 minutes, thus fatigue was considered not relevant; and
   - **Influence among subjects** it could not be really controlled. Subjects took the experiment under supervision of a human observer. We believe that this issue did not affect the internal validity.
4) **Threats to External Validity:** two threats were detected:
   - **Instrumentation:** failing to use real use case models, as the e-commerce PL is not commercial. More experimental studies must be conducted using real PLs, developed by industry; and
   - **Subjects:** lecturers and graduate students of Software Engineering were selected. However, more experiments taking into account industry practitioners must be conducted, allowing to generalizing the study results.

TABLE II
SPERMAN'S CORRELATION BETWEEN X AND Y EFFECTIVENESS AND THE SUBJECTS KNOWLEDGE LEVEL.

The X Approach (PLUS)						
Subject #	Effectiveness	r_{a1}	Knowledge Level	r_{b3}	$r_{a1} - r_{b1}$	$d1^2$
1	1,00	4	5	6	-2	4
2	9,00	6	3	1	5	25
3	7,00	3	2	2	1	1
4	5,00	2	2	3	-1	1
5	5,00	5	2	4	1	1
6	5,00	10	2	5	5	25
7	-1,00	7	2	8	-1	1
8	-1,00	12	2	9	3	9
9	-3,00	8	2	10	-2	4
10	-3,00	9	2	11	-2	4
11	-3,00	11	2	12	-1	1
12	-1,00	1	1	7	-6	36

The Y Approach (SMarty)						
Subject #	Effectiveness	r_{a2}	Knowledge Level	r_{b2}	$r_{a2} - r_{b2}$	$d2^2$
1	-7,00	10	5	12	-2	4
2	7,00	7	4	5	2	4
3	5,00	3	4	7	-4	16
4	5,00	11	4	8	3	9
5	11,00	5	3	1	4	16
6	7,00	6	3	4	2	4
7	-1,00	1	3	9	-8	64
8	11,00	12	2	2	10	100
9	9,00	4	2	3	1	1
10	-1,00	2	2	10	-8	64
11	-1,00	8	2	11	-3	9
12	7,00	9	1	6	3	9

IV. CONCLUSION

New theories and technologies must be experimented before they can be transferred to industry and effectively be adopted by software engineering practitioners. In this paper, it is shown how the effectiveness of a variability management approach (SMarty) can be analyzed to facilitate and improve variability activities in a PL perspective.

This experimental study is important to provide a means to demonstrate the ability to use the variability management approaches (PLUS and SMarty). An effectiveness calculation was done for each approach based on the application of the approaches theory for variability representation in use case models. This calculation allowed us to identify the more effective approach for use case models taking into account the e-commerce PL proposed by Gomaa [4].

Shapiro-Wilk normality test was applied to the data collected from the subjects, which demonstrated the normality of such a collected data. Therefore, the parametric T-test technique was applied providing evidence that SMarty is more effective than PLUS. As a last step of this study, it was performed a correlation between the variability knowledge level of the subjects and the effectiveness of each approach. Spearman ranking correlation technique provided evidence that, for PLUS, the previous knowledge on variability was important to guide the subjects on correctly identify variabilities in use case models. On the other hand, for SMarty, such a previous knowledge was not important for one to identify and represent variabilities in use case models. One of the main reasons might be the fact that SMarty provides a set of guidelines to identify and represent variabilities, making such an activity easier.

New experimental studies and replications must be planned and conducted to make it possible to reduce the threats, increasing the effectiveness of SMarty and generalizing the results. As new experiments, we are: (i) planning an effectiveness analysis of SMarty for class models taking into consideration PLUS; (ii) planning a replication of this study to corroborating the obtained results; and (iii) planning an experiment for effectiveness analysis of SMarty for sequence models.

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