Empirical Research in Software Process Modeling: A Systematic Literature Review

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Abstract—Recognized as one of the powerful technologies in software process engineering, Software Process Modeling (SPM) has received significant attention over the last three decades. Although empirical research plays a critical role in software engineering, the state-of-the-practice of empirical research in SPM has not been systematically reviewed. This paper serves as a status report of the assessment of empirical research in SPM by analyzing all refereed studies that were published in relevant venues from 1987 to 2008 using systematic review methodology. The primary findings indicate that in current SPM-related empirical studies, (1) software process management and improvement (SPI) was not yet the most popular primary research objectives; (2) exploratory empirical research methods, e.g., case study and action research, were dominantly used; (3) there were common issues in empirical research reports in terms of following rigorous reporting guidelines. Based on the review results, we also suggest the future needs for empirical research in SPM, in terms of research topics, SPM techniques, the strengths of research methodology and the rigors of empirical studies.

Keywords—Software process modeling and simulation, empirical research, systematic literature review

I. INTRODUCTION

Software Process Modeling (and Simulation) (SPM) refers to the activities in creating abstract representations of the methodology, design or definition of the software process, i.e., the software development process models [1]. SPM research, which includes both static modeling and dynamic (simulation) modeling research, provides the packages of techniques and powerful tool sets that leverage the planning, understanding, managing and improving systems and software processes. Empirical research in SPM plays a critical role by gathering the current best evidence from SPM research and practices, which can be integrated into the software process management and improvement practices. It is particularly useful to understand the best practices and lessons learned in applying various SPM techniques, and the strength of their empirical evidence.

Systematic Literature Review (SLR) is a key research method to gather and analyze all evidence available on specific topics. However, such secondary study has not been systematically reported in SPM-related empirical studies yet, especially in analyzing the strength of empirical evidence. Our research objective is to report the state-of-the-practice of empirical research in SPM in the methodological perspectives of empirical research, and provide convincing and illuminating supports for its future improvements.

This paper presents an SLR of SPM-related empirical studies published in domain specific venues including 7 journals and 6 conference proceedings, plus other relevant studies found by searching across online digital libraries, in the period of 1988 to December 2008. The SLR results are based on data collected/synthesized from 43 SPM-related empirical studies, finally selected from 326 relevant studies.

The reminder of this paper is organized as follows. Section II explains our review methodology. Section III presents our review results and discusses our findings based on the data we have collected in the review. Section VI concludes the paper and envisions the direction of future research.

II. RESEARCH METHOD

This study followed Kitchenham and Charters’s methodological guidelines for SLR [2]. It went through 8 major steps of the review process including Define Research Questions, Develop Search Strategy, Develop and Update Review Protocol, Find Relevant Studies, Review and Extract Data, Analyze and Synthesize Data, Quality Assessment and finally Format and Compile Report (some steps were performed simultaneously). Due to the space limitation, we only reported the most important steps in the following sections. A detailed description of our research methods, including study inclusion and exclusion criteria, quality assessment checklists etc. can be found in [3].

A. Research Questions

Based on the research objectives in Section I, our research was guided by the following four questions about the empirical research in SPM:

RQ.1 What are the primary research objectives?
RQ.2 What SPM techniques have been used or evaluated?
RQ.3 What empirical research methods and data analysis techniques have been employed?
RQ.4 How rigorous are the studies (with regard to the empirical research guidelines, e.g., the guidelines for empirical research in software engineering [4])?
B. Implementations

Finding Relevant Studies. The relevant studies in this SLR were defined as published studies on SPM until December 2008, which observed and reported empirical evidences in either academic or industrial settings. The above date put an upper bound of studies included in this review. We also kept the starting point of the time frame open, trying to trace back the literature as early as possible. Our search strategy employed a two-step approach, including (1) an initial manual search on 12 domain specific venues\(^1\) and (2) a complimentary Quasi-Gold Standard technique\(^2\), refined automated search across 5 different digital libraries\(^3\), using search strings synthesized with Software, Process, Development, Model and Simulation and their variants (e.g., Modeling, Models etc. for Model).

Study Selection. The study selection process included: (1) an initial selection, which was conducted by reviewing the title and abstract of the publication (the paper’s structure, conclusion, or reference was further checked when an exclusion decision could not be made based on them); and (2) a final selection, which was conducted by excluding duplicate publications, original versions of the extended or detailed (continuous) publications, and publications that did not report SPM-related empirical evidence from the initial selection. However, in most cases, whether a study is an empirical study can only be determined during the review. After the final selection, we reviewed each selected study. Only when we could identify any empirical evidence from that study, the study would be further assessed, extracted, analyzed and reported regarding our research questions.

Due to the space limitation, we only reported a portion of our findings to be discussed in the following sections.

A. The Primary Research Objectives (RQ.1)

The primary research objectives of SPM-related empirical studies have been identified and classified into 4 categories, with regard to the their strength of assimilating software process improvement (SPI): Process Understanding, Process Management and Improvement, SPM Technique Evaluation and Others.

As shown in Table II, SPM Techniques Evaluation (41.9%) is the most common primary research objective of the SPM-related empirical studies, followed by Process Understanding (25.6%). It is surprising that only 14.0% of the empirical studies were targeted for (Software) Process Management and Improvement (SPI), which should be the ultimate goal of SPM research. This is primarily due to the facts that: (1) the deployment of SPI activities is limited by the contexts (e.g., politics of organization); (2) it is difficult

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1. Journals, including TSE, IEEE Software, TOSEM, SPIP, JSME, JSS, IST, and conference proceedings of ICSE and related workshops, ICSP, ProSim, PROFES and EuroSPI
2. Including ACM digital library, IEEE Xplorer, SpringerLink, Science Direct and Wiley Interscience
3. Available at http://systematicreviews.org

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III. Results and Findings

We finally include 43 SPM-related empirical studies\(^4\) for this SLR. These SPM-related empirical studies were published from the year 1987 to December 2008. Figure 1 shows the number of selected studies published in each calendar year, denoted on the top of the vertical bar. We can observe a significant increase of the number of empirical studies since 1999, which was primarily due to the steadily expanding of SPM research and its research community, e.g., the emerging and expanding ProSIM and ICSP, which encouraged significant attentions and research in SPM.

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4. The complete list of selected studies is available at http://www.mendeley.com/groups/923651/list-of-spm-related-empirical-studies/papers/.
to systematically collect and organize SPI-related empirical data due to organizations’ proprietary issues; and (3) it may take decades to obtain and report SPI empirical evidence for the deployment of a new SPM approaches.

B. SPM Techniques (RQ.2)

We have identified 15 SPM techniques in the SPM-related empirical studies. The number of studies deploying these techniques, for process static or dynamics modeling, is shown in Figure 2. System Dynamics (SD) (10, 23.3%) and Hybrid Simulation combining System Dynamics and Discrete-Event Simulation (Hybrid(SD+DES))(5, 11.6%) were the top two deployed modeling techniques. There were 10 studies without specific technique deployed. Figure 2 shows that Little-JIL and Object Petri-Ner have been applied in both dynamic and static modeling.

Figure 2. The number of studies reporting different techniques

Table III

<table>
<thead>
<tr>
<th>Research Method</th>
<th>Data Analysis</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Action Research</td>
<td>12 Qualitative</td>
<td>12</td>
<td>27.9%</td>
</tr>
<tr>
<td>Case Study</td>
<td>13 4</td>
<td>13</td>
<td>30.2%</td>
</tr>
<tr>
<td>Experiment</td>
<td>4 4</td>
<td>8</td>
<td>9.3%</td>
</tr>
<tr>
<td>Meta-analysis</td>
<td>3 1</td>
<td>4</td>
<td>7.0%</td>
</tr>
<tr>
<td>Phenomenology</td>
<td>9 1</td>
<td>10</td>
<td>20.9%</td>
</tr>
<tr>
<td>Survey</td>
<td>3 2</td>
<td>5</td>
<td>7.0%</td>
</tr>
<tr>
<td>Sub-Total</td>
<td>43 9</td>
<td>43</td>
<td></td>
</tr>
</tbody>
</table>

* One study claimed using both case study and controlled experiment [6].

C. Empirical Research Methods and Data Analysis Techniques (RQ.3)

Capturing the main research methods of the selected studies, we summarized the statistics in Table III, with regard to the categorization from psychological research according to Christensen [7]. Case Study (30.2%), Action Research (27.9%) and Phenomenology (20.9%) were popular research methods in selected studies. Case Study was the most frequently used empirical method, due to its flexibilities in empirical data collections and research design.

On the other hand, Table III shows that explanatory (definitive) empirical methods, e.g., Experiment (9.3%), Meta-analysis (7.0%) and Survey (7.0%) were rarely used in SPM-related empirical studies. This is probably due to that collecting software process empirical data for use in these research methods is extremely expensive.

“When I was at TRW with a fair amount of management clout, I was not able to do this kind of experimentation on TRW projects. I had to go teach at USC or UCLA to get comparable teams to test hypotheses on prototyping.”

Another interesting question is what research method has been used the most frequently to serve specific research objectives. Table II shows that Case Study was the most frequently used in the studies whose primary research objective were Process Understanding (72.7%) and SPM Techniques Evaluation (66.7%). This indicates that Case Study was preferred when the nature of research was exploratory, i.e., to investigate the possible impacts of process change or to show the applicability of a specific SPM technique. Action research (80.0%) was the most frequently used in studies to “influence or change some aspect of whatever is the focus of the research” [8] (SPI). This also provides evidence to support the assertion that “In software process improvement, the research method should be characterized as action research” [9].

Table III lists the distribution of included studies using Qualitative or Quantitative data analysis techniques, with regard to the empirical research methods used. Compared with Qualitative analysis, Quantitative analysis was less used in the empirical research in SPM. We found that Qualitative analysis was used in all 43 included studies, among which 9 studies also applied Quantitative analysis.

Quantitative analysis is often used to yield statistical results and conformance evidences to data models, e.g., to test hypothesis etc. However, in SPM domain, researchers are apt to attribute more significance to a single statistically significant finding in support of a hypothesis, because empirical findings are scarce in this field. The empirical data used in Qualitative analysis were based on small but focused sample sets, rather than large sample sets used in Quantitative analysis. The major role of Quantitative analysis in SPM-related empirical studies was to provide supports for qualitative empirical evaluations.

D. Rigor in Reporting Empirical Research (RQ.4)

We have evaluated the rigor of each empirical study report, in terms of how well it conformed to the proposed reporting structures by the empirical research guidelines [4]. Table IV lists the top two missing sections (Experimental Design and Execution) in the SPM-related empirical studies. The percentage of the studies which actually included

5We did not include literature surveys studies, as they were not primary SPM-related empirical studies and has conflict interests with this paper.

Dr. Barry Boehm’s comment on the obstacles on conducting experiments in empirical software engineering, 2009
rigorous descriptions of Experimental Design is 13.95%, and which included Execution is 23.26%. These observations are worth future attentions of researchers to improve the quality of empirical research reports in SPM.

Table IV

<table>
<thead>
<tr>
<th>Section</th>
<th>Number of Studies</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>All studies</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>Research Design</td>
<td>6</td>
<td>13.95%</td>
</tr>
<tr>
<td>Execution</td>
<td>10</td>
<td>23.26%</td>
</tr>
</tbody>
</table>

IV. Discussion

Characteristics of Empirical Research in SPM. In general empirical software engineering research [10] [11], explanatory research methods, (e.g., Experiment) have been used as much as exploratory research methods, (e.g., Case Study), especially in well established domains such as requirements engineering [12]. In emerging research domains, e.g., SPM and Global Software Engineering [13], exploratory research methods, especially Case Study and Action Research, were frequently used to generate hypothesis using limited empirical data rather than to test established hypothesis. Moreover, the availability of empirical data for SPM is relatively scarce compared to other software engineering domains, such as Open Source Software development, etc.

Future Improvement for Empirical Research in SPM. Based on our observations presented in this SLR, we suggest future empirical research in SPM in the following aspects:

1. Using explanatory empirical research methodology. Currently the empirical studies in SPM were mostly exploratory in nature, whose strengths of empirical evidence were relatively weak. Although large sets of SPM-related empirical data are expensive to collect, the employment of these explanatory research methods (e.g., Experiment(s) and Survey(s)) could improve the strengths of the empirical evidence. We encourage more SPM-related empirical studies to use these explanatory empirical methods whenever it is possible. Moreover, the researcher should be clear about the pros and cons between the exploratory and explanatory empirical research methods, and be careful in claiming their usage in the study reports.

2. Improving the rigor of empirical research report in SPM. The most common issue of SPM-related empirical studies is not following a rigorous style or structure in reporting empirical research. Even it sometimes is reasonable (e.g., space limitations), however, the quality of report of empirical research is sacrificed, by e.g., missing research methods etc. Thus we recommend researchers to rigorously follow definitive empirical study reporting guidelines.

V. Conclusions and Future Work

This paper reports the state-of-the-practice of the empirical research in SPM based on our SLR results and suggests potential improvements for future SPM-related empirical studies, especially in the perspectives of empirical research methodologies and rigors in reporting research.

Our future work will (1) continue to report this SLR based on updated set of SPM-related empirical studies and (2) develop methodological and technical supports to effectively reuse existing empirical evidences in the SPM domain.

REFERENCES


