A Systematic Review of Software Reliability Studies

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Abstract- This paper aims to provide a basis for the improvement of software reliability research through a systematic review of previous works. The review identifies 141 papers on software reliability in 34 journals and classifies the papers according to research topic, research approach, and study context. The review results combined with other knowledge provide the support for recommendations for future research on software reliability, including 1) increase the breadth of the search for relevant studies, 2) search manually for relevant papers within a carefully selected set of journals when completeness is essential, and 3) conduct more studies on reliability methods commonly used by the software industry.

Keywords- software reliability models, approaches, analysis

1. INTRODUCTION

This study reviews journal articles on software reliability with the goal of supporting and directing future reliability researches. Our review has the following elements:

- **Different goal:** While the main goal of this review is to direct and support future reliability researches, the other reviews principally aim at introducing software practitioners or novice reliability researchers to the variety of formal reliability models. This difference in goal leads to a different focus. For example, our review focuses on research methods and does not include a comprehensive description of different software reliability methods.

- **More comprehensive and systematic review:** We based the analysis on a systematic search of journal papers, which led to the identification of 141 journal papers from 34 journals. We did not find any such review describing a systematic selection process or state clear criteria for inclusion or exclusion.

- **Classification of studies:** We classified the software reliability papers with respect to research topic, research approach, and study context.

Based on what we believed were interesting issues to analyze, we posed five research questions described in Table 1. The underlying motivation for all questions was our goal of improvement of the software reliability researches. These research questions guided the design of the review process.

The remaining part of this paper is organized as follows: Section 2 describes the review process. Section 3 reports the review results. Section 4 summarizes the main recommendations for future researches on Software Reliability.

2. REVIEW PROCESS

2.1 Inclusion criteria

The main criterion for including a journal paper in our review is that the paper describes research on software reliability models. Papers related to Software Reliability are only included if the main purpose of the studies is to improve Software Reliability process. We excluded pure discussion/opinion papers.

There were examples of papers describing, essentially, the same study in more than one journal paper. Fortunately, the number of such cases was small and would not lead to important changes in the outcome of our analysis. We, therefore, decided not to exclude any paper for that reason.
TABLE 1
RESEARCH QUESTIONS

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Main Motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ1: Which and how many journals include papers on Software Reliability?</td>
<td>Support Software Reliability researchers with a list of journals with potentially relevant papers.</td>
</tr>
<tr>
<td>RQ2: To what extent are Software Reliability researchers aware of the breadth of potential Software reliability sources?</td>
<td>Identify possible shortcomings of Software Reliability researchers’ searches for related work.</td>
</tr>
<tr>
<td>RQ3: How easy is it to identify relevant Software Reliability journal papers?</td>
<td>Identify possible shortcomings of internet and library based searches to identify Software Reliability papers.</td>
</tr>
<tr>
<td>RQ4: What are the most investigated Software Reliability search topics and methods and how has this changed over time?</td>
<td>Identify the trends and possible shortcoming / opportunities for research topic and method focus.</td>
</tr>
<tr>
<td>RQ5: What are the most frequently applied research methods, and in what study context? How has this changed over time?</td>
<td>Identify the trends and possible shortcoming / opportunities for the use of research methods.</td>
</tr>
</tbody>
</table>

2.2 Identification of papers

The search for papers was based on an issue-by-issue, manual reading of titles and abstracts of all published papers, written in English in various journals published in IEEE Xplore, Springer, ACM, Wiley, Elsevier, Questia and Sage. The journals were identified through reading the reference list of software reliability papers, searching on internet for previously not identified, relevant journals. Both authors constructed a list of potentially relevant journals independently. These two journals were merged together. In spite of the good number of identified journals, it is possible that there are, e.g. national or company-specific journals with papers on software reliability that we have missed.

Papers that were potential candidates for inclusion in our review were read more thoroughly to decide whether to include them or not. In total, 141 relevant papers were found in 34 journals. These 34 journals and 141 papers are listed in, respectively, Appendices A and C. The search was completed in May 2011.

2.3 Classification of papers

For the purpose of our analysis, i.e., addressing the research questions, we have classified the papers according to the properties and categories listed in Table 2. The categories are explained in Appendix B. The categories are adapted to the needs of our analysis. In particular, the classification aims at answering the research questions RQ4, and RQ5. The classification schema was developed for the purpose of our review and is not intended to be a general-purpose classification of software reliability studies. We believe, however, that the classification may be useful for other researchers searching for relevant papers on, for example, a particular reliability approach. Note that most of the categories are nonexclusive, e.g., a paper may focus on more than one reliability approach and apply more than one research model. The robustness of the classification schema and process was evaluated by testing a random sample of papers. The classification test showed that several of the initial descriptions of categories were vague. Most of the disagreements were due to recurring issues, e.g., different interpretations regarding how much review of previous studies a paper should include to be classified as a review paper. In other words, the main problem was the clarity of the descriptions and not so much the initial classification itself. We therefore decided that the initial classification had a degree of accuracy sufficiently high for the purpose of this paper, given that we: 1) clarified the descriptions that led to disagreements, and 2) reclassified the papers that belonged to the problematic categories. In spite of this effort to improve the reliability of the classification, it is likely that several of our classifications are subject to discussion, that the descriptions could be improved further, and that some of the papers are classified incorrectly. However, we believe that on the whole, the current classification is of sufficiently high quality to serve the purpose of our analysis.

TABLE 2
CLASSIFICATION OF PAPERS

<table>
<thead>
<tr>
<th>Property</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research topic</td>
<td>Model, Analysis, Use of statistics, Test Plan, Approach, Others</td>
</tr>
<tr>
<td>Research approach</td>
<td>Survey, Theory, Experiment, Case Study, Review, Simulation</td>
</tr>
<tr>
<td>Study context</td>
<td>Students and/or Professors, Professional and/or Industrial software projects, Not relevant</td>
</tr>
</tbody>
</table>
2.4 Analysis

The classification of research papers provided a general picture of the characteristics of the software reliability research. This general picture served as a starting point for deeper investigation of findings that seemed, from our perspectives, to suggest important shortcomings in reliability research and possibilities for improvement.

2.5 Threats to validity

The main threats to the validity of our review, we have identified, are these:

Publication bias: The exclusion of conference papers and reports is based mainly on practical concerns, including workload, e.g., the problems of identifying all relevant papers and the amount of analysis needed to handle the fact that many journal papers are improvements of previously published conference papers. However, we are interested mainly in properties of the research into software reliability. The main bias of our inclusion of journal papers is simply one toward papers with high scientific quality. We probably have excluded a major source of information about the software industry’s experience in using different reliability approaches. Our analyses and recommendations try to reflect this bias. Another potential publication bias is that which might result from not publishing reliability research that has no significant results, results that did not yield the desired outcome, company-confidential results, or results that were conducted on topics that do not fit into the common software engineering journals. Also, only those papers were included which were available free of cost and paid papers were excluded. The size and effect of the potential publication biases would be interesting to study but would require a study design different from ours. Vested interest of the authors: We are not aware of the biases we may have had when categorizing the paper. It is possible that the recommendations we make are affected by our interests and opinions.

Unfamiliarity with other fields: Clearly, reliability is a topic that is relevant to many fields; thus, it is possible that we have overlooked essential work and relevant journals published in another discipline, e.g. medical science.

3. Results

3.1 Relevant Software Reliability Research Journals (RQ1)

We found papers on software reliability in as many as 34 journals, i.e., the total number of journals with such papers are higher than we expected. The 34 journals are listed in Appendix A. The name of the journal with five or more papers on software reliability is also displayed in Table 3, together with the corresponding number, proportion and cumulative proportion of papers. These six journals include two-thirds (65.90%) of all identified journal papers on software reliability. Reading only the top five most relevant journals means that important results may be missed.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Journal</th>
<th>Number of Relevant Papers Found</th>
<th>Proportion</th>
<th>Cumulative Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IEEE Transactions on Software Engineering</td>
<td>41</td>
<td>29.07%</td>
<td>29.07%</td>
</tr>
<tr>
<td>2</td>
<td>Software IEEE</td>
<td>21</td>
<td>14.89%</td>
<td>43.97%</td>
</tr>
<tr>
<td>3</td>
<td>Journal of Systems and Software</td>
<td>15</td>
<td>10.63%</td>
<td>54.53%</td>
</tr>
<tr>
<td>4</td>
<td>Electronics and Communications in Japan</td>
<td>6</td>
<td>4.25%</td>
<td>58.80%</td>
</tr>
<tr>
<td>5</td>
<td>Annals of Software Engineering</td>
<td>5</td>
<td>3.55%</td>
<td>62.35%</td>
</tr>
<tr>
<td>5</td>
<td>Empirical Software Engineering</td>
<td>5</td>
<td>3.55%</td>
<td>65.90%</td>
</tr>
</tbody>
</table>

3.2 Researcher Awareness of Relevant Journals (RQ2)

We were interested in the degree to which software reliability researchers were aware of and systematically searched for related research in more than a small set of journals. An indication of this awareness was derived through a random selection of 15 software reliability journal papers (above 10% of the journal). These papers are
marked with (S) in Appendix C. The reference lists of each of these papers were examined. From this examination, we found that:

- The typical (median) software reliability study relates its work to and/or builds on Software Reliability studies found in only a few different journals, esp. in IEEE TSE. 12 out of 15 (80%) of the selected papers referred to this journal, for example, in paper “Analyzing and Improving Reliability: a tree based approach”, 37.50% paper referred were from IEEE TSE. 33.33% selected papers also referred to IBM Journal of Research and Development. We examined the topics of the papers and found that some of the papers did not refer to previously published, seemingly relevant, papers on the same research topic. For example, “A sequential Bayesian generalization of the Jelinski–Moranda software reliability model” by Alan Washburn, published in 2006 in Naval Research Logistics (NRL) journal by Wiley did not mentioned the name of the journal paper “A Bayesian modification to the Jelinski–Moranda software reliability model” by Bev Littlewood and Ariela Sofer, published in journal Software Engineering Journal in 1987 by IEEE Xplore. This indicates, we believe, that many papers on Software Reliability are based on information derived from a rather narrow search for relevant papers.

- The most referenced journal, with respect to related Software Reliability work, was the IEEE Transactions on Software Engineering (IEEE TSE) and it contained maximum number of papers (29.07%). Reliability papers from this journal were referred to 15 as many as 80 percent of the papers. There were surprisingly many references (33.33%) to IBM Journal of Research and Development. 20 percent papers also referred to Journal of System and Software.

- Few papers referred to papers published outside the software community like “Estimation of Software Reliability by Stratified Sampling” and “Software Reliability Models: Assumptions, Limitations, and Applicability” referred to “Estimating software reliability from Test Data” by E.N. NELSON, published in Microelectronics in 1978 and “A Sequential Bayesian Generalization of the Jelinski–Moranda Software Reliability Model” referred to journals like “American Institute of Aeronautics and Astronautics” and “IEEE Trans Aerospace 2”.

- Also, some journals outside computer science field also published paper on reliability improvement and referred to papers from IEEE TSE. Paper “Improving the Reliability of Medical Software by Predicting the Dangerous Software Modules” was published in the Journal of Medical Systems.

The above evidence indicates that several authors use narrow criteria when searching for relevant software reliability papers. The most important issue, however, is whether papers on software reliability miss prior result that would improve its study. This can not be derived from our view alone. Our impression, however, based on the review presented in this paper, is that the major deviation from what we assess as the best research practice is the lack of identification and integration of results outside the computer science domain.

3.3 Identification of Relevant Software Reliability Research Journal Papers (RQ3)

Our search for software reliability papers was, as described earlier, based on a manual issue-by-issue search from the journal. This is, we believe, an accurate method of identifying relevant research papers, given that the people conducting the search possess sufficient expertise. It does, however, require much effort and, if possible, it should be replaced with more automated search and identification methods. The main tool for this is the use of digital libraries. To indicate the power of the digital libraries we conducted the following evaluation:

1. The search term: “software reliability” was applied in many journals. Wider searches would, obviously, lead to more complete searches. The number of “false alarms” would, however, also increase strongly and the benefit of automatic search may easily disappear.

2. The papers identified by using the above searches were compared with the set of papers from our manual search.

The main conclusion from this simple test was that the use of the search facilities of digital libraries to search for common software reliability terms is not sufficient for the identification of all relevant software reliability research papers. The search in many journals missed a substantial part of relevant papers.

A closer examination of the titles and abstracts of the journal papers not identified suggests that the most typical reasons for non-identification in our test were:

- When we typed “software reliability”, all papers, around 314, appeared, as “software” appeared
on each paper in the journal “IEEE Transactions on Software Engineering”, out of only 41 were relevant, which were found by manual issue-by-issue search.

- A variety of substitutes for the term “reliability,” e.g., “fault tolerant”, etc were used.
- A variety of terms used instead of “software,” e.g., “system,” “project,” and “program”, etc.
- Use of more specific terms derived from particular reliability methods, e.g., “Bayesian analysis,” instead of more general reliability terms like “Enhancing software reliability”.
- Studies dealing with specific reliability topics, e.g., “Reliability estimation for a software system with sequential independent reviews” may not use the general “reliability” term.

In many cases, a software reliability researcher will use more specific terms when searching for relevant papers. This may reduce the effect of the last two of the above reasons and higher coverage rates can be expected. However, there remains the problem that a number of synonyms are used for the terms “reliability” and “software.” A wider search, e.g., the search (“software” AND (“reliability”) identified the paper. In addition, if we had used variants of the terms, e.g., “reliable” instead of “reliability,” we would not have identified the paper in spite of a very wide search. It is evident that searches in digital libraries that are sufficiently wide to identify relevant software reliability estimation research can easily lead to higher workload than purely manual search processes.

Manual searches do not guarantee completeness, either. It is easy to make errors and to miss relevant journals. The current situation, with a lack of standardized terminology, may require a manual search of titles and abstracts in a carefully selected set of journals to ensure the proper identification of relevant research on software cost estimation. In the longer term, enforcing a more standard scheme of classification for software reliability or a more standardized use of keywords should be an important goal for digital libraries and researchers on software reliability.

### 3.4 Distribution of Research Topics (RQ4)

Table 4 shows the distribution of topics for three periods and in total. The distribution in Table 4 suggests that:

- The most common research topic, with 42.85% of the papers, is the “analysis” of various models and trends in Software Reliability.
- The distribution of topics over time is quite stable, with a few exceptions. Papers on the “analysis” were more common before 1990 (about 55%) indicating that before 1990’s, as study of software reliability was in its nascent stage, less studies were conducted then (13% only of overall studies) and it was simply of analyzing, in nature, of models proposed by others, relatively few by researchers(15%).
- Though, more models were proposed in later period (14.35%), but their analysis by others increased significantly (42.85%) , it shows that researchers are less interested in proposing new things, rather, they either relied upon examining old thing or improving it.
- There is also huge increase in number of different approaches proposed for Software reliability in the three decades, from 15% of total studies before 1990 to 32.90% of total studies after 2000 contributing to overall of 29.22% of total papers examined, which directly links to increase in number of analysis as more and more people were analyzing other’s work so after that, they proposed improvements on them.

Table 4 indicates that the most papers on software reliability are of “analysis” in nature, analyzing various software reliability models and effects of other theories on software reliability, etc. Also, using Statistical techniques declined after 1990. Publisher-wise distribution of data is given in Appendix D (of IEEE Xplore, Elsevier, Wiley, Springer, Questia, ACM, and Sage).

<table>
<thead>
<tr>
<th>Research topics</th>
<th>~1989</th>
<th>1990-1999</th>
<th>2000-2011</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Models</td>
<td>3(15.00%)</td>
<td>8(13.79%)</td>
<td>12(15.78%)</td>
<td>23(14.35%)</td>
</tr>
<tr>
<td>Analysis</td>
<td>11(55.00%)</td>
<td>24(41.37%)</td>
<td>31(40.78%)</td>
<td>66(42.85%)</td>
</tr>
<tr>
<td>Use of Statistics</td>
<td>2(10.00%)</td>
<td>0(0%)</td>
<td>0(0%)</td>
<td>2(1.30%)</td>
</tr>
<tr>
<td>Test plans</td>
<td>0(0%)</td>
<td>5(8.62%)</td>
<td>4(5.26%)</td>
<td>9(5.84%)</td>
</tr>
<tr>
<td>Approaches</td>
<td>3(15.00%)</td>
<td>17(25%)</td>
<td>25(32.90%)</td>
<td>45(29.22%)</td>
</tr>
<tr>
<td>Others</td>
<td>1(5.00%)</td>
<td>4(9.31%)</td>
<td>4(5.26%)</td>
<td>9(5.84%)</td>
</tr>
</tbody>
</table>

One paper may discuss more than one topic.
3.5 Research Approach and Study Context (RQ5)

Table 5 shows the distribution of papers applying different research approaches, per period, and in total.

Table 5 suggests that:

- Even now, major portion of studies in this area is theoretical in nature, for example, studying models, describing and analyzing them and/or proposing an improvement over them, etc. (63.08%).
- Excluding theoretical studies, major papers evaluate software reliability using through case studies (16.77%) and after that comes experiments (13.51%), in the form of mathematical derivation, investigation, and/or implementation, and reviews (11.40%) and very few uses simulation techniques (2.68%).

In short, there seems to be a lack of in-depth practical studies on the actual use of software reliability method/models which were published as journal papers. Moreover, about 63.08% of total studies conducted are still theoretical in nature, which basically analyzes other’s studies models and/or proposes an improvement or alternate way to them, and there is still lack of experimental studies (only 13.51%). Publisher-wise distribution of data is given in Appendix D (of IEEE Xplore, Elsevier, Wiley, Springer, Questia, ACM, and Sage).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey</td>
<td>0(0%)</td>
<td>0(0%)</td>
<td>2(2.94%)</td>
<td>2(1.34%)</td>
</tr>
<tr>
<td>Theory</td>
<td>12(54.54%)</td>
<td>41(69.50%)</td>
<td>41(60.20%)</td>
<td>94(63.08%)</td>
</tr>
<tr>
<td>Experiment</td>
<td>3(13.63%)</td>
<td>9(15.25%)</td>
<td>13(19.11%)</td>
<td>25(13.51%)</td>
</tr>
<tr>
<td>Case study</td>
<td>2(9.09%)</td>
<td>4(6.77%)</td>
<td>1(1.47%)</td>
<td>7(16.77%)</td>
</tr>
<tr>
<td>Review</td>
<td>5(22.72%)</td>
<td>3(5.08%)</td>
<td>9(0%)</td>
<td>17(11.40%)</td>
</tr>
<tr>
<td>Simulation</td>
<td>0(0%)</td>
<td>2(3.38%)</td>
<td>2(13.23%)</td>
<td>4(2.68%)</td>
</tr>
</tbody>
</table>

One paper may apply more than one approach

More over before 2000, substantial number of studies were conducted at industry levels but it declined after 2000 (11.48%). It can also be concluded that out of the total publication in software reliability, the contribution by universities (either by student or professor or both) has increased drastically and enjoys a dominant share of overall studies.

<table>
<thead>
<tr>
<th>Study context</th>
<th>~1989</th>
<th>1990-1999</th>
<th>2000-2011</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>St</td>
<td>9(47.36%)</td>
<td>54(52.42%)</td>
<td>109(73.64%)</td>
<td>172(63.46%)</td>
</tr>
<tr>
<td>Pr</td>
<td>8(42.10%)</td>
<td>33(32.03%)</td>
<td>17(11.48%)</td>
<td>58(21.40%)</td>
</tr>
<tr>
<td>Nr</td>
<td>3(15.78%)</td>
<td>16(15.53%)</td>
<td>22(14.86%)</td>
<td>41(15.13%)</td>
</tr>
</tbody>
</table>

The abbreviations used are: St: students and/or professors, Pr: professional and/or industrial software projects, Nr: not relevant

One paper may apply more than one study context

4. CONCLUSION

This paper reviews software reliability papers published in journals classified according to research topic, research approach, and study context. Based on our, to some extent subjective, interpretation of the review results and other knowledge, we recommend the following changes in reliability research:

- **Increase the breadth of the search for relevant studies**: Software reliability research studies seem, on average, to be based on searches for relevant previous studies that use few sources. If the goal is to find relevant research on software
reliability, it is not sufficient to conduct searches in digital libraries or manual searches of the most important software engineering journals. We identified as many as 34 journals with studies on software reliability, several software reliability papers that would have been hard to find through searches in digital libraries, and many journals from other domains that contained relevant results.

- **Search manually for relevant papers in a carefully selected set of journals when completeness is essential:** There is a lack of standardized use of terms pertaining to software reliability. We believe that such a lack makes it easy to miss important papers when relying on automatic searches in digital libraries or getting more than required papers. The search term “software reliability” for example, identified more than thousands of papers on software reliability by using automatic search. We are aware of the practical limitations related to the use of manual search process, e.g., the required search effort. In cases where completeness is not essential, a combination of manual search of the most relevant journals and use of digital libraries to cover the other journals may be sufficient.

- **Conduct more studies on reliability methods commonly used by the software industry:** In spite of the fact that formal reliability models have been in existence for many years, the dominant reliability method is based on expert judgment. Further, available evidence does not suggest that the reliability prediction accuracy improves with use of formal reliability models. Also, as majority of these papers analyzed are of theoretical in nature relating to analysis or approach and are conducted at university level. This shows that maximum of these papers may be written just for formality, either by students for obtaining their degree or by faculties for their promotion, etc. Despite these factors, current research, which is industry specific or of practical use, is relatively sparse and we believe that this area deserves more research effort.

We cannot claim, based on empirical evidence, that adherence to our recommendations actually leads to better software reliability predictions. However, adherence to these recommendations will, we believe, increase the probability that future reliability research builds on existing knowledge, is relevant for the software industry and is easier to generalize to other contexts. This in turn, we think, will increase the probability of better reliability predicting methods and reliability practices.

**REFERENCES**


**APPENDIX A**

(The numbers of papers identified in each paper are in ()). The titles of journals with more than five papers appear in italic.)

*Annals of Software Engineering (5) - rank 5*
*Applied Stochastic Models in Business and Industry (21)*
*Automation and Remote Control (1)*
*Cybernetics and Systems Analysis (1)*
*Electronics and Communications in Japan (6) - rank 4*
*Empirical Software Engineering (5) - rank 5*
*IBM Journal of Research and Development (1)*
*IBM systems Journals (2)*
*IEEE Proceedings Software (1)*
*IEEE Transactions on Software Engineering (41) - rank 1*
*Information and Software Technology (3)*
*Innovations in Systems and Software Engineering (4)*
*International Journal of Automation and Computing (2)*
*International Journal of Systems Assurance Engineering and Management (3)*
*Journal of Applied Mathematics and Computing (1)*
*Journal of Computer Science and Technology (1)*
*Journal of Mechanical Engineering Science (1)*
*Journal of Medical Systems (1)*
*Journal of Risk and Reliability (1)*
*Journal of Shanghai University (English Edition) (1)*
*Journal of Systems and Software (15) - rank 3*
*Journal of the ACM (JACM) (1)*
*Journal of the American Statistical Association (1)*
*Naval Research Logistics (NRL) (1)*
*Programming and Computer Software (1)*
*Quality and Reliability Engineering International (2)*
*Sadhana (1)*
*Software Engineering Journal (4)*
*Software IEEE (21) - rank 2*
*Software Quality Journal (1)*
*Software Testing, Verification and Reliability (3)*
*The American Statistician (2)*
*Transactions on Software Engineering and Methodology (TOSEM) (2)*
*Wuhan University Journal of Natural Sciences (4)*
APPENDIX B

CLASSIFICATION DESCRIPTIONS

Category: Research topic

1. Models: Studies of various software reliability models, simple theoretical studies only.
2. Analysis: Studies dealing with impact of various factors on software reliability or criteria for model comparisons, etc.
3. Use of statistics: Studies dealing with statistical inferences made or statistical estimation done on software reliability.
4. Test plans: Studies dealing with test plans for inferences on software reliability.
5. Approaches: Studies proposing various new/alternate approaches to improve software reliability process.
6. Other topics: Unclassified topics.

Category: Research approach

1. Survey: Survey-based studies, e.g., questionnaire and interview-based surveys of industry practice.
2. Theory: Studies dealing with theoretical description/evaluation of properties of various software reliability models and/or proposing new models or approach.
3. Experiment: Studies dealing with criteria for assessments and model comparisons, experiment-based studies, mathematical derivations, systematic investigations and/or practical implementations of some models, etc.
4. Case study: Case-based studies, e.g. in-dept study of processes of one or more projects.
5. Review: Studies that review other software reliability papers/models.
6. Simulation: Simulation-based studies. This category relates to the research method, e.g., the evaluation method.

Category: Study context

1. Students: Studies where the subjects are students, professors and/or student projects.
2. Professionals: Studies where the subjects are software professionals and/or industrial software projects.
3. Not relevant: Studies where the study context is not relevant.

APPENDIX C

JOURNAL PAPERS ON SOFTWARE

Software Reliability and Testing Time Allocation: An Architecture-Based Approach,
Pietrantuono, R.; Russo, S.; Trivedi, K.S.;
Software Engineering, IEEE Transactions on Volume: 36 , Issue: 3 Digital Object Identifier: 10.1109/TSE.2010.6 Publication Year: 2010, Page(s): 323 – 337 Publisher: IEEE Xplore

Uncertainty Analysis in Software Reliability Modeling by Bayesian Analysis with Maximum-Entropy Principle,
Yuan-Shun Dai; Min Xie; Quan Long; Szu-Hui Ng;

Nonparametric Analysis of the Order-Statistic Model in Software Reliability,
Simon P. Wilson; Francisco J. Samaniego;

A simulation approach to structure-based software reliability analysis
Gokhale, S.S.; Michael Rung-Tsong Lyu;

Evaluating Web software reliability based on workload and failure data extracted from server logs,
Tian, J.; Rudraraju, S.; Zhao Li;

A unified scheme of some Nonhomogenous Poisson process models for software reliability estimation,
Chin-Yu Huang; Lyu, M.R.; Sy-Yen Kuo;

Reliability estimation for a software system with sequential independent reviews,
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APPENDIX D

PUBLISHER-WISE DISTRIBUTION OF DATA

Category: Research topic

IEEE XPLORC

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<th>1990-1999</th>
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<td>6(14.63%)</td>
<td>2(18.18%)</td>
<td>11(15.27%)</td>
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<td>17(41.46%)</td>
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<td>4(9.75%)</td>
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One paper may discuss more than one topic.

WILEY

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ABOUT THE AUTHORS:

**Apoorva Singhal**: Mr. Singhal is a final year M.Tech (Information Technology) student from Guru Gobind Singh Indraprastha University, Kashmere Gate. He obtained his B.Tech from Galgotias College of Engineering and Technology, Greater Noida in Computer Science branch. He is a GATE qualified student, was also associated with HCL as a software engineer after completion of his graduation. Beside Neural Networks, his other areas of interests are Expert system, compiler technology, principles of programming language, Vaastu Shastra and medical science. He developed an expert system on Vaastu shastra as his final year B.Tech project in CLIPS. Currently, he is working on implementation of disease diagnosis system using Neural Network.

**Ankur Singhal**: Mr. Singhal is a final year B-Tech student of prestigious institute HBTI Kanpur. Since the very beginning of his academic career, he has been focusing on the various technologies in computer science field. He is very keen in implementation of these technologies into real life projects. He is well versed with various programming languages like C, C++, JAVA, MATLAB, LISP etc. He is simultaneously working on a number of different projects. Apart from ‘Dental Implant Simulation Software’, he has also worked upon the optimization of Ad-hoc routing protocols by adding link prediction algorithm for quality improvement and added the code in the Network Simulator-2 software.