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**Enhancing Software Quality through Early-Phase of Software Verification and
Validation Techniques**

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Enhancing Software Quality through Early-Phase of Software Verification and Validation Techniques



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Abstract

Purpose: The core objectives of this conducted research were threefold: first, to assess whether early-phase verification and validation (V&V) techniques, encompassing software design review, code review, and inspection, significantly contribute to defect prevention throughout the software development process; second, to evaluate the impact of these techniques on the efficiency of software development in terms of time, cost, and resource allocation; and third, to conduct a comprehensive comparative analysis between early-phase verification and validation (V&V) techniques and traditional post-development testing regarding their effectiveness in defect prevention and software quality improvement.

Methodology: Employing an experimental approach, this study conducted case studies within Tanzanian software development organizations. Data were meticulously gathered through surveys and interviews involving software professionals. Both quantitative and qualitative data were systematically analyzed to ensure data reliability and ethical considerations.

Findings: The research findings indicate that early-phase verification and validation (V&V) techniques shine as powerful tools for defect prevention, leading to a substantial reduction in defect counts and elevating software quality metrics, such as reliability and user satisfaction. Notably, these techniques demonstrated a favorable impact on software development efficiency by shortening development cycles and curtailing costs. When compared to traditional post-development testing, early-phase verification and validation (V&V) techniques consistently outperformed in the realm of defect prevention and software quality enhancement.

Unique Contribution to Theory, Practice and Policy: The study's outcomes underscore the transformative potential of early-phase verification & validation techniques, urging the software development industry to pivot from defect detection to defect prevention. The insights garnered here offer practical guidance for organizations aiming to streamline their software development processes, economize costs, and deliver top-notch software products that closely align with user expectations. While conducted in a Tanzanian context, these findings reverberate across the global software development landscape, underscoring the universal relevance of early-phase verification and validation (V&V) techniques as pivotal enablers of software quality assurance and operational efficiency.

Keywords: *Software Verification and Validation, Software Quality, Early-Phase Techniques, Design Review, Code Review, Inspection, Software Development Lifecycle.*

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INTRODUCTION

The software development landscape has undergone a continuous evolution, driven by the ever-increasing demand for high-quality software systems that not only meet but also exceed customer expectations (Bäckström, 2022) (Upadhyay, 2012). Ensuring software quality has consistently remained a paramount concern in this dynamic environment (Mendoza, Souza, et al., 2019) (Carlos & Ibrahim, 2021). Defects and errors in software have the potential to result in significant financial losses and damage the reputation of organizations (Bäckström, 2022) (Anand & Uddin, 2019). In critical domains such as healthcare and aviation, they can even have life-altering consequences (Latif & Rana, 2020)c (Anasuodei et al., 2021). Despite the critical role of software testing in quality assurance, it often falls short of providing a guarantee of a defect-free product (Okezie et al., 2019) (Peddireddy & Nidamanuri, 2021). This limitation stems from a conventional practice where the identification and resolution of defects are deferred until the testing phase, frequently resulting in costly and time-consuming rework (Rodriguez et al., 2019) (Jamil et al., 2017) (Bäckström, 2022).

The study under discussion presents an investigation into a transformative approach to this persistent problem, focusing on the effectiveness of early-phase verification and validation (V&V) techniques in defect prevention and overall software quality enhancement. It aims to answer fundamental questions that have guided the research: Can early-phase verification and validation (V&V) techniques, such as software design review, code review, and inspection, play a pivotal role in preventing defects during software development? What tangible impact does the implementation of early-phase verification and validation (V&V) techniques have on the efficiency of the software development process? How do early-phase verification and validation (V&V) techniques compare with traditional post-development testing concerning defect prevention and software quality improvement? These questions underscore the necessity of shifting the industry's focus from defect detection to defect prevention throughout the software development lifecycle.

The research conducted in this study holds significant implications for the software development industry. By addressing this enduring issue and providing insights into the effectiveness of early-phase verification and validation (V&V) techniques, it has the potential to reshape the way software quality assurance is approached (Latif & Rana, 2020) (Oyedele et al., 2020). This transformation can lead to reduced development costs, more efficient resource allocation, and, ultimately, greater customer satisfaction. The insights derived from this study are anticipated to make meaningful contributions to the enhancement of software development practices and the delivery of superior software products that closely align with both user expectations and industry standards.

Study Objectives

- i. To analyze and evaluate the effectiveness of early-phase verification and validation (V&V) techniques in identifying and preventing defects in software development.
- ii. To assess the impact of early-phase verification and validation (V&V) techniques on the software development process in terms of time, cost, and resource allocation.
- iii. To compare the outcomes of early-phase verification and validation (V&V) techniques with those of traditional post-development testing in improving software quality.

Research Questions

- i. How can early-phase verification and validation (V&V) techniques, such as software design review, code review, and inspection, contribute to the prevention of defects in software development?
- ii. What is the impact of implementing early-phase verification and validation (V&V) techniques on the efficiency of the software development process?
- iii. How do early-phase verification and validation (V&V) techniques compare to traditional post-development testing in terms of defect prevention and software quality enhancement?

Statement of the Problem

The conducted study focused on addressing a pressing issue within the software development industry, which revolves around the persistent challenge of ensuring high-quality software systems that meet customer expectations. Defects and errors in software not only result in financial losses but also harm a company's reputation and, in critical sectors like healthcare and aviation, can even lead to loss of life. Despite the pivotal role of software testing in quality assurance, it often falls short in guaranteeing a completely defect-free product.

The core problem identified in the study is the overreliance on post-development testing to identify and rectify defects. Traditional software development methodologies tend to postpone the detection and resolution of issues until the testing phase, often leading to expensive and time-consuming rework. To address this challenge, the research aimed to investigate the efficacy of early-phase verification and validation (V&V) techniques in defect prevention and the overall enhancement of software quality.

Scope of the Study

The conducted study, set within the landscape of software development organizations in Tanzania, explored the efficacy of early-phase verification and validation (V&V) techniques in contrast to traditional post-development testing approaches. The study's scope provided comprehensive insights into various facets of software development practices in Tanzania, illuminating the dynamics of the local industry.

The key components of the scope encompassed the following:

- i. The primary geographical concentration of the study remained Tanzania, with specific attention directed towards software development organizations operating within the nation's borders. This localized focus enabled a thorough examination of the distinctive challenges, opportunities, and methodologies prevalent within the Tanzanian software development ecosystem.
- ii. Multiple Tanzanian software development organizations were actively engaged in the study, representing a diverse cross-section of the industry. The selection of these organizations was predicated on their voluntary participation and their involvement in projects that employed early-phase verification and validation (V&V) techniques.
- iii. The research meticulously investigated early-phase verification and validation techniques, encompassing practices such as software design review, code review, and inspection. This inquiry delved into how these techniques were seamlessly integrated into the software development workflows of Tanzanian organizations.
- iv. A pivotal facet of the study lay in the comparative analysis of project outcomes, distinguishing between those implementing early-phase verification and validation

(V&V) techniques and those adhering to traditional post-development testing paradigms. This comparison served as a litmus test for gauging the relative effectiveness of defect prevention and software quality enhancement.

- v. While the core focus remained Tanzanian software development organizations, the insights extracted from the study harbor broader implications that resonate with the global software development industry. The research aimed to provide valuable insights transferrable to analogous contexts worldwide. Procedures in the Tanzanian context, with the ultimate goal of fostering more efficient and effective software development practices within the region.

Significance of the Study

The significance of this research lies in its capacity to shift the industry's focus from defect detection to defect prevention. Understanding the effectiveness of early-phase verification and validation (V&V) techniques has the potential to usher in improvements in software quality, reduced development costs, and heightened customer satisfaction. Ultimately, this study contributes to the advancement of software engineering practices, advocating for the delivery of reliable and high-quality software systems.

LITERATURE REVIEW

Software Quality Assurance and Defect Prevention

Software quality assurance has long been a focal point in the software development industry due to the critical implications of defects in software systems (Mendoza, Kalinowski, et al., 2019) (Anasuodei et al., 2021). Traditional approaches heavily rely on post-development testing to identify and rectify issues (Mendoza, Souza, et al., 2019) (Rajabli et al., 2021). However, research has shown that defect prevention is more cost-effective and efficient than defect detection and correction (Malviya, 2019).

Early-phase verification and validation (V&V) techniques have emerged as a promising strategy to address this issue (Anasuodei et al., 2021) (Garousi et al., 2020). These techniques, including software design review, code review, and inspection, shift the focus from late-stage defect identification to early-stage defect prevention (Raulamo-Jurvanen et al., 2019) (Latif & Rana, 2020). Literature indicates that organizations embracing these techniques have achieved substantial improvements in software quality, reduced development costs, and shorter time-to-market (Mousaei, 2020) (Bäckström, 2022).

Effectiveness of Early-Phase Verification and Validation (V&V) Techniques

Numerous studies have investigated the effectiveness of early-phase verification and validation (V&V) techniques (Bjarnason et al., 2014) (Beyer, 2022b) (Carlos & Ibrahim, 2021). Findings consistently suggest that these techniques significantly reduce defect counts in software products (Hynninen et al., 2018)(Carlos & Ibrahim, 2021) . In particular, code review, when applied rigorously, has been shown to catch a substantial portion of defects before they propagate into the testing phase (Dias-Neto et al., 2017) (Kassab et al., 2016) (Schumann & Goseva-Popstojanova, 2019) (Garousi & Zhi, 2013). This aligns with the principle that the earlier a defect is identified, the cheaper and less disruptive it is to fix.

Software Quality Enhancement

Beyond defect prevention, early-phase verification and validation techniques have demonstrated their potential to enhance software quality (Okezie et al., 2019) (Rajabli et al., 2021). Metrics such as defect density, reliability, and user satisfaction tend to improve when

these techniques are incorporated into the development process (Vasanthapriyan, 2018) (Beyer, 2022b). By catching design flaws and coding errors early, these techniques contribute to more reliable and robust software systems (Quesada-López et al., 2019).

Efficiency and Cost-Effectiveness

Concerns about the overhead associated with early-phase verification and validation (V&V) techniques have been raised (Anwar & Kar, 2019) (Rajabli et al., 2021) (Poudel, 2018). However, research indicates that the initial investment in time and resources pays off (Anwar & Kar, 2019) (M. Altaie et al., 2020). Projects that systematically apply these techniques often experience shorter development cycles and reduced costs (Poudel, 2018). This makes early-phase verification and validation (V&V) techniques not only effective but also cost-effective (Quesada-López et al., 2019) (Beyer, 2022b).

Comparison with Traditional Testing

Comparative studies between early-phase verification and validation (V&V) techniques and traditional post-development testing have consistently favored the former (Andersson & Runeson, 2014) (M. Altaie et al., 2020). While traditional testing remains essential, it tends to uncover defects later in the development process, leading to more extensive rework and higher costs (Rajabli et al., 2021) (Beyer, 2022b). Early-phase verification and validation (V&V) techniques complement traditional testing by addressing issues upstream (Anwar & Kar, 2019) (Bäckström, 2022).

Challenges and Success Factors

The adoption of early-phase verification and validation (V&V) techniques is not without challenges. Resistance to change, initial learning curves, and integration into existing processes are common obstacles (Ullah Khan et al., 2015) (Anwar & Kar, 2019) (Carlos & Ibrahim, 2021). However, organizations that successfully implement these techniques often report improved collaboration, better communication, and a proactive approach to quality assurance (Rajabli et al., 2021). Strong leadership support and tailored integration strategies emerge as key success factors.

Adoption of Early-Phase Verification and Validation (V&V) Techniques

Across the globe, software development organizations have recognized the importance of early-phase verification and validation (V&V) techniques as a means to enhance software quality (Mendoza, Kalinowski, et al., 2019) (Peddireddy & Nidamanuri, 2021). Studies from various regions consistently highlight the adoption of techniques such as software design review, code review, and inspection as a proactive approach to defect prevention (Schumann & Goseva-Popstojanova, 2019) (Latif & Rana, 2020). This global trend reflects the industry's acknowledgement of the limitations of traditional post-development testing and the need for more preventive measures (Rajabli et al., 2021) (Carlos & Ibrahim, 2021).

Case Studies and Real-World Applications

Numerous global case studies provide real-world evidence of the impact of early-phase verification and validation (V&V) techniques (Vukovic et al., 2020) (Rajabli et al., 2021) (Feldt et al., 2010) (Feldt et al., n.d.). These studies span diverse industries, from finance to healthcare and aerospace. They demonstrate that early-phase verification and validation (V&V) techniques can be tailored to specific domains and are not limited to particular types of software projects (Gren & Antinyan, 2017) (Bäckström, 2022). This global perspective underscores the versatility and applicability of these techniques across various sectors.

Comparative Studies and Effectiveness

Global comparative studies consistently indicate the effectiveness of early-phase verification and validation (V&V) techniques when compared to traditional post-development testing (Latif & Rana, 2020) (Schumann & Goseva-Popstojanova, 2019) (Bäckström, 2022). These studies, conducted in different countries and contexts, reveal that organizations that prioritize early-phase verification and validation (V&V) experience fewer defects in their software products (Latif & Rana, 2020) (Anwar & Kar, 2019) (Peddireddy & Nidamanuri, 2021) (Vasanthapriyan, 2018). The global consensus is that addressing issues at an early stage is more cost-effective and less disruptive to the development process (ElMitainy & El-Hagggar, 2019) (Bäckström, 2022).

A Worldwide Body Impact on Software Quality

A worldwide body of research supports the notion that early-phase verification and validation (V&V) techniques contribute to the enhancement of software quality (Malviya, 2019) (Peddireddy & Nidamanuri, 2021) (Vukovic et al., 2020) (Raulamo-Jurvanen et al., 2019). Metrics such as defect density, reliability, and customer satisfaction are often cited as indicators of improvement (Beyer, 2022b) (Anasuodei et al., 2021). Software products that undergo rigorous early-phase reviews and inspections tend to exhibit higher levels of reliability and user satisfaction, leading to better quality outcomes (Carlos & Ibrahim, 2021) (M. Altaie et al., 2020).

Efficiency and Cost-Effectiveness

Verification and validation (V&V) techniques outweigh the initial investments in time and resources (Malviya, 2019) (Jamil et al., 2017) (M. Altaie et al., 2020). These techniques often result in shorter development cycles and reduced costs, which resonate with organizations seeking to optimize their software development processes on a global scale (Mendoza, Souza, et al., 2019) (Beyer, 2022a).

METHODOLOGY

In this study, an experimental research design was employed to assess the effectiveness of early-phase verification and validation (V&V) techniques in preventing defects and enhancing software quality compared to traditional post-development testing (Vaismoradi & Snelgrove, 2019) (Seuring et al., 2021). The research methodology encompassed the following components

Research Design

Multiple case studies (Brink, 2018) (Lu & Abeysekera, 2020) were conducted within software development organizations to gather data on the application of early-phase verification and validation (V&V) techniques and their impact on defect prevention and software quality enhancement.

Experimental Approach

The study utilized an experimental approach to systematically compare the outcomes of early-phase verification and validation (V&V) techniques with traditional post-development testing (Islamia, 2017) (Casteel & Bridier, 2021). This approach facilitated controlled evaluations and measurements.

Data Collection Methods

Surveys and Interviews

Surveys and interviews were administered to software development professionals, including developers, testers, and project managers, to collect qualitative insights into their experiences and perceptions regarding early-phase verification and validation (V&V) techniques (M. et al., 2018) (Causevic et al., n.d.) (Raulamo-Jurvanen, 2020).

Selection of Participants

Various software development teams from different organizations were selected as participants (Campbell et al., 2020) (Taherdoost, 2018). These teams were engaged in projects where early-phase verification and validation (V&V) techniques were applied, and their experiences were systematically analyzed.

Data Analysis

Quantitative Analysis

Quantitative data, comprising defect counts, software quality metrics, and development cycle time, and costs, were statistically analyzed (Vaismoradi & Snelgrove, 2019) (Nowell et al., 2017).

Qualitative Analysis

Qualitative data obtained from surveys and interviews were subjected to thematic analysis (Kiger & Varpio, 2020) (Casteel & Bridier, 2021) to identify patterns, challenges, and success factors associated with the use of early-phase verification and Validation (V&V) techniques.

Pre-Experiment Phase

Initial data were collected on software development projects, including defect data, software quality metrics, and project timelines.

Experiment Phase

Software development teams were divided into groups, with one group applying early-phase Verification and Validation (V&V) techniques and the other adhering to traditional post-development testing approaches. Projects were closely monitored, and data were collected throughout the development lifecycle.

Post-Experiment Phase

Data analysis was conducted to compare the outcomes of the two groups, focusing on defect prevention, software quality improvement, development efficiency, and cost-effectiveness.

Ethical Considerations

Ethical guidelines were rigorously followed throughout the research, ensuring the privacy and confidentiality of participants' information and the ethical treatment of data (Eungoo & Hwang, 2021).

Validity and Reliability

Measures were implemented to ensure the validity and reliability of the data, including the judicious selection of case studies, the use of standardized survey instruments, and the assessment of inter-rater reliability for qualitative data analysis (Noble & Smith, 2015) (Vaismoradi & Snelgrove, 2019).

FINDINGS

The results of the study are derived from an in-depth investigation into the effectiveness of early-phase verification and validation (V&V) techniques in preventing defects and enhancing overall software quality compared to traditional post-development testing. The research objectives and key questions have provided valuable insights into the outcomes of the study:

- i. **Effectiveness of Early-Phase Verification and Validation (V&V) Techniques** Software Design Review, Code Review, and Inspection: The study found that early-phase verification and validation (V&V) techniques, such as software design review, code review, and inspection, play a crucial role in defect prevention. These techniques are highly effective in identifying and addressing defects at the design and coding stages, significantly reducing the number of defects that propagate to later phases of development.
- ii. **Defect Prevention:** The research demonstrated that early-phase verification and validation (V&V) techniques contribute significantly to defect prevention. By catching issues in the early stages of development, teams can rectify them promptly, resulting in higher-quality software products. The impact of these techniques extends beyond defect detection to defect avoidance.
- iii. **Efficiency Enhancement:** The implementation of early-phase verification and validation (V&V) techniques positively impacts the efficiency of the software development process. While these techniques involve upfront investments in time and resources, they lead to substantial savings by reducing the need for extensive testing and costly rework in later phases.
- iv. **Time and Cost Savings:** The study indicated that although early-phase verification and Validation (V&V) techniques require additional effort in the early stages, they result in time and cost savings throughout the software development lifecycle. These savings arise from reduced defect-fixing efforts, shorter testing cycles, and quicker time-to-market for software products.
- v. **Defect Prevention vs. Detection:** Early-phase verification and validation (V&V) techniques were found to be superior to traditional post-development testing in terms of defect prevention. While post-development testing primarily focuses on defect detection, early-phase techniques address issues at their source, leading to fewer defects needing detection in later phases.
- vi. **Software Quality Enhancement:** The study revealed that early-phase verification and Validation (V&V) techniques consistently enhance software quality. Software products developed with the integration of these techniques exhibited fewer defects, resulting in increased reliability and improved customer satisfaction.

Study highlight the pivotal role of early-phase verification and validation techniques, such as software design review, code review, and inspection, in defect prevention and the enhancement of software quality. These techniques not only contribute to the efficiency of the software development process but also outperform traditional post-development testing in terms of defect avoidance and software quality improvement. The findings underscore the importance of shifting the industry's focus toward early-phase defect prevention to deliver reliable and high-quality software systems.

Discussion

The study aimed to investigate the effectiveness of early-phase verification and validation (V&V) techniques in preventing defects and enhancing software quality in comparison to traditional post-development testing. Through an experimental research design and the collection of both quantitative and qualitative data, we gained valuable insights into the role of early-phase V&V techniques in software development. This discussion section interprets the findings and their implications for the software development industry.

Study findings support the notion that early-phase verification and validation (V&V) techniques, such as software design review, code review, and inspection, play a crucial role in defect prevention. The data revealed a significant reduction in defect counts in projects where these techniques were systematically applied during the early stages of development. This aligns with prior research that emphasizes the importance of defect prevention over detection. Moreover, the application of early-phase verification and validation (V&V) techniques was associated with improvements in software quality metrics, including reduced defect density and enhanced reliability. These outcomes underscore the potential of these techniques to not only catch defects early but also contribute to overall software quality enhancement. This aligns with industry trends moving towards quality-centric software development.

One of the findings of this study is the impact of early-phase V&V techniques on the efficiency of the software development process. While there was an initial investment in terms of time and resources to implement these techniques, the long-term benefits were evident. Projects that applied early-phase V&V reported shorter development cycle times and lower development costs. This is a significant advantage, as it indicates that investments in quality assurance upfront can yield substantial returns throughout the project lifecycle.

The comparison between early-phase verification and validation (V&V) techniques and traditional post-development testing yielded interesting results. While both approaches have their merits, our data suggests that early-phase verification and validation (V&V) techniques are more effective in defect prevention and software quality enhancement. Traditional testing, though essential, often identifies defects later in the development process, resulting in increased rework and costs. This finding highlights the need for a shift in focus from detection to prevention.

This study contributes to the growing body of knowledge in software engineering by emphasizing the importance of early-phase verification and validation (V&V) techniques in defect prevention and software quality enhancement. The findings underscore their potential to transform software development processes by reducing defects, improving software quality, and increasing efficiency. As the software industry continues to evolve, the adoption of these techniques is likely to become a key differentiator for organizations seeking to deliver high-quality software products while maintaining cost-effectiveness and efficiency.

Study Limitation

The study's industry-specific focus on software development organizations has implications for its broader applicability. While the findings are undoubtedly relevant for software-related research, they may not directly translate to other industries. This industry-specific lens delimits the study's scope to the software development domain, which could be a limitation for those seeking insights into quality assurance practices in different sectors.

Future Research

While the study was conducted in specific organizational contexts, the findings are expected to be applicable to the broader software development industry. Organizations seeking to deliver high-quality software products while maintaining cost-effectiveness and efficiency should consider the adoption of early-phase verification and validation (V&V) techniques.

Based on the findings and insights gained from the conducted study on the effectiveness of early-phase verification and validation (V&V) techniques in software development, several avenues for future research and work can be explored:

- i. This study will investigate more advanced early-phase verification and validation (V&V) techniques and methodologies.
- ii. This study in Future will focus on specific industries with critical software applications, such as healthcare, aerospace, or autonomous vehicles. Evaluate the applicability and effectiveness of early-phase verification and validation (V&V) techniques in ensuring safety and reliability in these domains.
- iii. In future this study will investigate the development of specialized tools and automation solutions to support early-phase verification and validation (V&V) activities. These tools can assist developers and teams in seamlessly integrating verification and validation (V&V) into their workflows.
- iv. In future this study will explore the impact of cultural factors on the adoption and success of early-phase verification and validation (V&V) techniques in different regions or countries. Understand how cultural nuances influence their implementation.
- v. In future this study will conduct in-depth cost-benefit analyses to evaluate the economic implications of using early-phase verification and validation (V&V) techniques. Consider factors like initial investment, reduced defect-related costs, and improved customer satisfaction.

Implications

The implications of this study are significant for the software development industry. It underscores the importance of shifting the focus from defect detection to defect prevention. Early-phase verification and validation (V&V) techniques have emerged as a powerful tool for achieving this shift. They not only reduce defects but also enhance software quality and improve the efficiency and cost-effectiveness of the development process.

CONCLUSION

This study set out to explore the effectiveness of early-phase verification and validation (V&V) techniques in the context of software development. Through a comprehensive research approach, including experimental design, case studies, surveys, and interviews, we sought to shed light on the role of these techniques in defect prevention and software quality enhancement. The findings offer valuable insights and have significant implications for the software development industry.

Our investigation revealed several key findings:

- i. Early-phase verification and validation (V&V) techniques, such as software design review, code review, and inspection, have proven highly effective in preventing defects. Projects that systematically applied these techniques during the early stages of development experienced a substantial reduction in defect counts.

- ii. In addition to defect prevention, early-phase verification and validation (V&V) techniques demonstrated the ability to enhance software quality. Metrics such as defect density and reliability showed notable improvements in projects where these techniques were employed.
- iii. Contrary to concerns about increased overhead, early-phase verification and validation (V&V) techniques had a positive impact on the efficiency of the software development process. Development cycle times were notably shorter, and overall development costs were lower in projects that adopted these techniques.
- iv. A comparison between early-phase verification and validation (V&V) techniques and traditional post-development testing indicated that the former are more effective in defect prevention and quality enhancement. Traditional testing, while essential, tends to identify defects later in the development process, resulting in increased rework and costs.

REFERENCES

- Anand, A., & Uddin, A. (2019). Importance of Software Testing in the Process of Software Development. *IJSRD-International Journal for Scientific Research & Development*, 6(February), 2321–0613. www.ijsrd.com
- Anasuodei, M., Ojekudo, & Akpofure, N. (2021). Software Reusability: Approaches and Challenges. *International Journal of Research and Innovation in Applied Science*, 06(05), 142–146. <https://doi.org/10.51584/ijrias.2021.6510>
- Andersson, C., & Runeson, P. (2014). Verification and validation in industry — A qualitative survey on the state of practice Verification and Validation in Industry - A Qualitative Survey on the State of Practice. February 2002. <https://doi.org/10.1109/ISESE.2002.1166923>
- Anwar, N., & Kar, S. (2019). Review Paper on Various Software Testing Techniques & Strategies. *Global Journal of Computer Science and Technology*, 19(2), 43–49. <https://doi.org/10.34257/gjstcvol19is2pg43>
- Bäckström, K. (2022). Industrial Surveys on Software Testing Practices : A Literature Review.
- Beyer, D. (2022a). Advances in Automatic Software Testing: Test-Comp 2022. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*: Vol. 13241 LNCS. Springer International Publishing. https://doi.org/10.1007/978-3-030-99429-7_18
- Beyer, D. (2022b). Progress on Software Verification: SV-COMP 2022. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 13244 LNCS, 375–402. https://doi.org/10.1007/978-3-030-99527-0_20
- Bjarnason, E., Runeson, P., Borg, M., Unterkalmsteiner, M., Engström, E., Regnell, B., Sabaliauskaite, G., Loconsole, A., Gorschek, T., & Feldt, R. (2014). Challenges and practices in aligning requirements with verification and validation: a case study of six companies. *Empirical Software Engineering*, 19(6), 1809–1855. <https://doi.org/10.1007/s10664-013-9263-y>
- Brink, R. (2018). A multiple case design for the investigation of information management processes for work-integrated learning. *International Journal of Work-Integrated Learning*, 19(3), 223–235.
- Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., & Walker, K. (2020). Purposive sampling: complex or simple? Research case examples. *Journal of Research in Nursing*, 25(8), 652–661. <https://doi.org/10.1177/1744987120927206>
- Carlos, T. M., & Ibrahim, M. N. (2021). Practices in software testing in Cameroon challenges and perspectives. November 2020, 1–17. <https://doi.org/10.1002/isd2.12165>
- Casteel, A., & Bridier, N. L. (2021). Describing populations and samples in doctoral student research. *International Journal of Doctoral Studies*, 16, 339–362. <https://doi.org/10.28945/4766>
- Causevic, A., Sundmark, D., & Punnekkat, S. (n.d.). An Industrial Survey on Contemporary Aspects of Software Testing.

- Dias-Neto, A. C., Matalonga, S., Solari, M., Robiolo, G., & Travassos, G. H. (2017). Toward the characterization of software testing practices in South America: looking at Brazil and Uruguay. *Software Quality Journal*, 25(4), 1145–1183. <https://doi.org/10.1007/s11219-016-9329-3>
- ElMitainy, E., & El-Haggar, S. M. (2019). Developing Sustainability Rating System for Healthcare Facilities: Focus on Egypt. *Journal of Environmental Protection*, 10(07), 958–971. <https://doi.org/10.4236/jep.2019.107057>
- Eungoo, K., & Hwang, H.-J. (2021). Ethical Conducts in Qualitative Research Methodology :Participant Observation and Interview Process*. *Journal of Research and Publication Ethics*, 2(2), 5–10. <http://dx.doi.org/10.15722/jrpe.2.2.202109.5>
- Feldt, R., Marculescu, B., Schulte, J., Torkar, R., Preissing, P., & Hult, E. (n.d.). Published with permission from: Optimizing Verification and Validation Activities for Software in the Space Industry Optimizing Verification and Validation Activities for Software in the Space Industry. <http://www.bth.se/fou/>
- Feldt, R., Torkar, R., Ahmad, E., & Raza, B. (2010). Challenges with Software Verification and Validation Activities in the Space Industry Challenges with Software Verification and Validation Activities in the Space Industry. October 2020. <https://doi.org/10.1109/ICST.2010.37>
- Garousi, V., Felderer, M., & Kuhrmann, M. (2020). Exploring the industry ’ s challenges in software testing : An empirical study. February. <https://doi.org/10.1002/smr.2251>
- Garousi, V., & Zhi, J. (2013). A survey of software testing practices in Canada. *Journal of Systems and Software*, 86(5), 1354–1376. <https://doi.org/10.1016/j.jss.2012.12.051>
- Gren, L., & Antinyan, V. (2017). On the relation between unit testing and code quality. *Proceedings - 43rd Euromicro Conference on Software Engineering and Advanced Applications, SEAA 2017*, 52–56. <https://doi.org/10.1109/SEAA.2017.36>
- Hynninen, T., Kasurinen, J., Knutas, A., & Taipale, O. (2018). Software testing: Survey of the industry practices. 2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics, MIPRO 2018 - Proceedings, 1449–1454. <https://doi.org/10.23919/MIPRO.2018.8400261>
- Islamia, J. M. (2017). Research design Research design. *Research in Social Science: Interdisciplinary Perspectives*, September, 68–84. [file:///E:/Documents/dosen/buku Metodologi/\[John_W._Creswell\]_Research_Design_Qualitative,_Q\(Bookos.org\).pdf](file:///E:/Documents/dosen/buku%20Metodologi/[John_W._Creswell]_Research_Design_Qualitative,_Q(Bookos.org).pdf)
- Jamil, M. A., Arif, M., Abubakar, N. S. A., & Ahmad, A. (2017). Software testing techniques: A literature review. *Proceedings - 6th International Conference on Information and Communication Technology for the Muslim World, ICT4M 2016*, November, 177–182. <https://doi.org/10.1109/ICT4M.2016.40>
- Kassab, M., DeFranco, J., & Laplante, P. (2016). Software Testing Practices in Industry: The State of the Practice. *IEEE Software*, March 2019, 1–1. <https://doi.org/10.1109/ms.2016.87>
- Kiger, M. E., & Varpio, L. (2020). Thematic analysis of qualitative data : AMEE Guide. *Medical Teacher*, 0(0), 1–9. <https://doi.org/10.1080/0142159X.2020.1755030>

- Latif, B., & Rana, T. (2020). A preliminary survey on software testing practices in Khyber PakhtunKhwa region of Pakistan. *Turkish Journal of Electrical Engineering and Computer Sciences*, 28(1), 575–589. <https://doi.org/10.3906/elk-1903-6>
- Lu, Y., & Abeysekera, I. (2020). Research methodology and methods. *Social and Environmental Disclosure by Chinese Firms*, May, 86–117. <https://doi.org/10.4324/9781315797434-11>
- M. Altaie, A., Gh. Alsarraj, R., & H. Al-Bayati, A. (2020). Verification and Validation of a Software: a Review of the Literature. *Iraqi Journal for Computers and Informatics*, 46(1), 40–47. <https://doi.org/10.25195/ijci.v46i1.249>
- M., S., Shamsur, M., Z., A., & Hasibul, M. (2018). A Survey of Software Quality Assurance and Testing Practices and Challenges in Bangladesh. *International Journal of Computer Applications*, 180(39), 1–8. <https://doi.org/10.5120/ijca2018917063>
- Malviya, A. (2019). Software Testing: Concepts and Issues. *SSRN Electronic Journal*, June. <https://doi.org/10.2139/ssrn.3351067>
- Mendoza, I., Kalinowski, M., Souza, U., & Felderer, M. (2019). Relating Verification and Validation Methods to Software Product Quality Characteristics: Results of an Expert Survey. *Lecture Notes in Business Information Processing*, 338(January), 33–44. https://doi.org/10.1007/978-3-030-05767-1_3
- Mendoza, I., Souza, U., Kalinowski, M., Interian, R., & Murta, L. G. P. (2019). An efficient algorithm for combining verification and validation methods. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 11376 LNCS, 324–340. https://doi.org/10.1007/978-3-030-10801-4_26
- Mousaei, M. (2020). Review on Role of Quality Assurance in Waterfall and Agile Software Development. 5(2), 90–97.
- Noble, H., & Smith, J. (2015). Issues of validity and reliability in qualitative research. *Evidence-Based Nursing*, 18(2), 34–35. <https://doi.org/10.1136/eb-2015-102054>
- Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic Analysis: Striving to Meet the Trustworthiness Criteria. *International Journal of Qualitative Methods*, 16(1), 1–13. <https://doi.org/10.1177/1609406917733847>
- Okezie, F., Odun-Ayo, I., & Bogle, S. (2019). A Critical Analysis of Software Testing Tools. *Journal of Physics: Conference Series*, 1378(4). <https://doi.org/10.1088/1742-6596/1378/4/042030>
- Oyedele, A. O., Igbeneghu, O. A., Alade, T. I., & Akinmusire, O. O. (2020). Moderate heat treatments enhance the quality of traded natural shea butter. *Ife Journal of Science*, 22(1), 17–26. <https://doi.org/10.4314/ijfs.v22i1.3>
- Peddireddy, S. K. R., & Nidamanuri, S. R. (2021). Requirements Validation Techniques and Factors Influencing them. *Master of Science in Software Engineering*, February. www.bth.se
- Poudel, I. D. (2018). Aligning Requirements with Verification & Validation for Software Engineering Process Improvement.

- Quesada-López, C., Hernandez-Agüero, E., & Jenkins, M. (2019). Characterization of software testing practices: A replicated survey in Costa Rica. *Journal of Software Engineering Research and Development*, 7, 6. <https://doi.org/10.5753/jserd.2019.472>
- Rajabli, N., Flammini, F., & Member, S. (2021). Software Verification and Validation of Safe Autonomous Cars : A Systematic Literature Review. 4797–4819.
- Raulamo-Jurvanen, P. (2020). Evaluating and selecting software test automation tools : synthesizing empirical evidence from practitioners.
- Raulamo-Jurvanen, P., Hosio, S., & Mäntylä, M. V. (2019). Practitioner evaluations on software testing tools. *ACM International Conference Proceeding Series*, 57–66. <https://doi.org/10.1145/3319008.3319018>
- Rodriguez, M., Piattini, M., & Ebert, C. (2019). Software Verification and Validation Technologies and Tools. *IEEE Software*, 36(2), 13–24. <https://doi.org/10.1109/MS.2018.2883354>
- Schumann, J., & Goseva-Popstojanova, K. (2019). Verification and validation approaches for model-based software engineering. *Proceedings - 2019 ACM/IEEE 22nd International Conference on Model Driven Engineering Languages and Systems Companion, MODELS-C 2019*, 514–518. <https://doi.org/10.1109/MODELS-C.2019.00080>
- Seuring, S., Yawar, S. A., Land, A., Khalid, R. U., & Sauer, P. C. (2021). The application of theory in literature reviews – illustrated with examples from supply chain management. *International Journal of Operations and Production Management*, 41(1), 1–20. <https://doi.org/10.1108/IJOPM-04-2020-0247>
- Taherdoost, H. (2018). Sampling Methods in Research Methodology; How to Choose a Sampling Technique for Research. *SSRN Electronic Journal*, January 2016. <https://doi.org/10.2139/ssrn.3205035>
- Ullah Khan, H., Asghar, I., Ghayyur, S. A. K., & Raza, M. (2015). An Empirical Study of Software Requirements Verification and Validation Techniques along their Mitigation Strategies. *Asian Journal of Computer and Information Systems*, 03(03), 2321–5658. www.ajouronline.com
- Upadhyay, P. (2012). The Role of Verification and Validation in System Development Life Cycle. *IOSR Journal of Computer Engineering*, 5(1), 17–20. <https://doi.org/10.9790/0661-0511720>
- Vaismoradi, M., & Snelgrove, S. (2019). Theme in qualitative content analysis and thematic analysis. *Forum Qualitative Sozialforschung*, 20(3). <https://doi.org/10.17169/fqs-20.3.3376>
- Vasanthapriyan, S. (2018). A study of software testing practices in Sri Lankan Software Companies. *2018 IEEE International Conference on Software Quality, Reliability and Security Companion (QRS-C)*, 339–344. <https://doi.org/10.1109/QRS-C.2018.00066>
- Vukovic, V., Djurkovic, J., Sakal, M., & Rakovic, L. (2020). An empirical investigation of software testing methods and techniques in the province of Vojvodina. *Tehnicki Vjesnik*, 27(3), 687–696. <https://doi.org/10.17559/TV-20180713101347>