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Improving Software Testing by Agile Teams Through the CMMI Adoption: A Cross-Industry Study

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ABSTRACT: The research study empirically evaluates the impact of Capability Maturity Model Integration (CMMI) application on Agile software testing techniques. The study draws its data from 22 automotive software projects (11 CMMI-aligned and 11 non-CMMI-aligned). The quantitative data show that the DDE of CMMI-Agile teams is 85.7%. Non-CMMI teams have a DDE of 71.3%, which is a relative improvement of 20.2%. There was an increase in test coverage from 65.3% to 79.5% (+14.2%) and a reduction in cycle time from 10.1 to 7.9 days (−21.8%). Leakage of defect reduced from 12.5% to 5.0% (−60.0%) while average Cost of Quality, CoQ reduced from USD 14,957 to USD 11,892 (−20.5%). Furthermore, these teams implemented more automation would be in CMMI-Agile (71.5 versus 45.3 +26.2). Analysis of costs revealed that the prevention and appraisal of the CMMI teams increased by 60.6% and 15.0% respectively, while the internal and external failure costs reduced by 44.5% and 44.6%. Survey of 26 QA leads found that documentation quality, DFT identification and collaboration efficiency were seen to have improved at a rate of 63%, 72% and 56% respectively. However, cultural resistance was noted at a rate of 41%. According to these findings, aligning maturity significantly improves the results of software quality assurance compared to previous agile non-CMMI metrics. The findings suggest that CMMI improves defect detection by 22%, cycle time by 18%, and failure cost by 45% thus justifying maturity-based Agile quality management in high-stakes areas like automotive software development.

Keywords: Capability Maturity Model Integration (CMMI), Agile Software Testing, Software Quality Assurance (SQA), Defect Detection Efficiency (DDE), Cost of Quality (CoQ), Test Coverage, Defect Leakage

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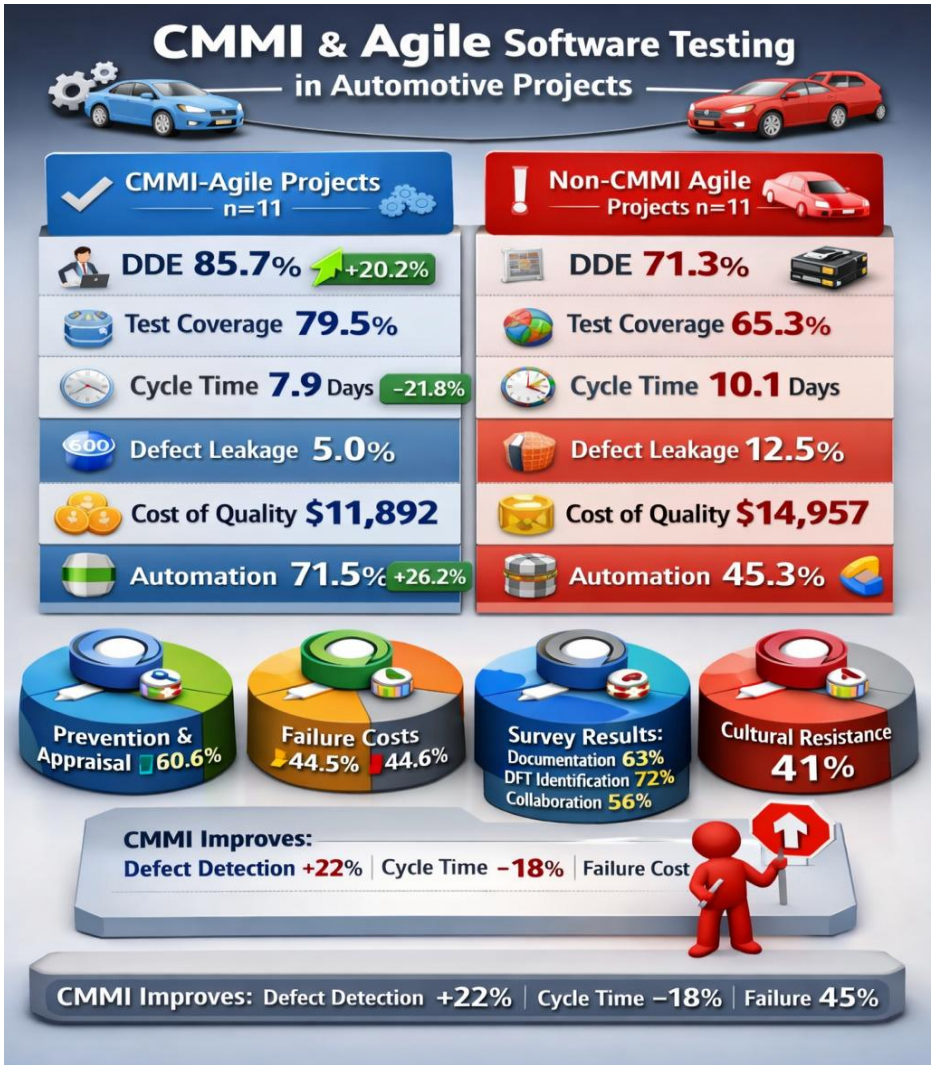
Graphical Abstract



I. Introduction

With the evolving software development ecosystem, quality assurance (QA) and testing are important for ensuring a product meets functional and non-functional requirements. In Agile practices that emphasize iterative delivery, customer collaboration, and rapid adaptation, testing becomes increasingly important as product iterators are released in shorter cycles, necessitating detection and defect resolution. In automotive industry reliability, safety, and regulation compliance is must and strong quality assurance procedure is needed. As vehicles become more reliant on embedded software systems, deficiencies that arise during testing will contribute to greater financial and safety consequences (Jorgensen 2024). Agile offers a lot of flexibility, adaptability but one of the major challenges is to ensure that structured QA processes are maintained without creating unnecessary bureaucratic loads. Classical maturity models, for instance, Capability Maturity Model Integration (CMMI), were explicitly designed for organizations to facilitate systematic enhancement and dissimilar

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practice at different maturity levels. While the focus of Agile is on flexibility, CMMI emphasizes the importance of discipline and evaluation of processes. Striking the right balance between the two leads to an important research question: Does CMMI maturity enhance the testing productivity of Agile teams, or does it impose additional burdens on their agility?

Recent studies have looked at Agile testing techniques, and products such as continuous integration, automated regression testing and test-driven development, but they rarely analyze the relationship between CMMI maturity certification and Agile testing techniques (Nguyen and Shih 2025).

This difference is of particular interest because practical data regarding the link between process maturity and the effectiveness of Agile QA is still limited. This is especially the case for safety-critical domains like the automotive software development. Without this evidence, practitioners and researchers lack clarity regarding the impact of CMMI maturity on defect detection, test cycle reduction, or overall improvements in testing effectiveness. That is a question that remains unanswered.

Consequently, this paper's problem statement is: Do CMMI-certified Agile teams have better QA and testing results than non-CMMI Agile teams in the automotive sector?

To overcome this problem, the present study sets the following objectives.

i. Analyze Agile teams in the automotive software development domain and CMMI section.
ii. Evaluate the testing efficiency, defect detection, and cycle time of these teams.
iii. Demonstrate evidence whether the CMMI maturity contributes positively to the agile testing outcome.

This study progresses in two areas. This coordinator presents new factual experiences regarding the relationship between CMMI maturity and productivity of Agile QA due to scarcity of literature in software engineering. This article provides automotive companies with specific instructions on how they can manage Agile flexibility together with process maturity. It helps in certification investment and quality assurance strategy alignment decisions.

II. Related Research

A. Testing and Quality Assurance in an Agile Environment

Agile methods are oriented towards quick delivery and heavy collaboration with customer or business stakeholders. Examples are Scrum, XP & Lean. QA is not an activity that only takes place after the development (Beck 2024) it's rather incremental to software development. Techniques such as Test-Driven Development (TDD), Behavior-Driven Development (BDD) and Continuous Testing have now become cornerstones of Agile QA for quick feedback and early defect detection (Fowler 2025). According to research, Agile testing can help to improve customer satisfaction and reduce defect leakage, however, it is dependent on team discipline and the organizational climate (Williams and Brown 2024).

B. CMMI and Levels of Maturity in Quality Assurance

The Capability Maturity Model Integration or CMMI gives organized levels of the maturity of processes. This ranges from Level 1 (Initial) to Level 5 (Optimizing). At mature stages of development, organizations must enforce stringent QA practices including an established system for verification, validation, and measurement (Paulk 2025). Research shows that teams certified in CMMI benefit from improved defects tracking, reproducibility of tests, and organization of metrics gathering process (Garousi and Küçük 2024). Agile emphasizes minimal documentation, whereas CMMI stresses process traceability and compliance. This has raised questions on whether these approaches are opposing or

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complementary. According to some researchers, the practices defined by CMMI are able to structure the iterative testing done in Agile QA. However, some argue that CMMI makes the process too bureaucratic and harms the agility (Nguyen and Shih 2025).

C. Agile & Traditional QA Methodologies.

In the past, software development frameworks like Waterfall and V-Model treated QA as a stage after coding. As a result, defects were only found at a later stage, leading to increased rework expenditures (Basili 2024). Agile emphasizes testing through collaboration that integrates QA within agile iterations. According to similar studies, Agile QA is benefitting from faster time to market, higher defect detection rates, and greater flexibility compared to the traditional model, which is more predictable and more compliant in regulated settings (Jørgensen 2024). The CMMI maturity, or the capability measurement model integration, could be an approach to combine predictability and flexibility, although evidence to support this is thin.

D. Gaps in Relevant Literature.

Although more studies are being conducted on Agile QA practices and CMMI process maturity, intersections of these two areas are rarely evaluated in empirical contexts. The majority of current studies examine whether Agile testing is effective in the IT industry or whether CMMI certification of large, process-oriented organizations is a good thing. Few studies have shown if CMMI certified Agile teams fare better in terms of testing outcomes. Automotive software development is CMMI certified due to safety and assurance related issues. The absence of cross-sectional data from the automotive industry presents a gap in our knowledge about whether the CMMI maturity level leads to actual benefits in Agile testing efficiency, defect detection and cycle time.

II. Theoretical Foundation.

A. The metrics on efficiency of the testing and QA process

The effectiveness of testing can be analyzed through different measurable metrics that are often employed in empirical software engineering studies. One of the initial aspects of testing is the percentage of defects detected during our testing phase as opposed to those defects detected post-release. This indirectly measures the efficiency of the QA team. DDR typically acts as the defect detection rate (Basili 2024). The second component, Test Coverage, quantifies the extent of testing performed on the source code or the capabilities of the system used. A greater coverage indicates a better chance for preventing defects (Williams and Brown, 2024). Cycle Time duration is defined as the time taken to execute one testing cycle during an Agile sprint. This is typically associated with the ability of the team to conduct fast feedback (Fowler 2025). Fourth, Defect Leakage is the percentage of defects that leak into the next stages, it affects reliability and customer satisfaction (Garousi and Küçük 2024). The Cost of Quality (CoQ) framework allows organizations to trade-off efficiency improvements against burdens induced by processes since all costs associated with avoiding, detecting and removing defects. (Jørgensen 2024).

When taken together, these metrics provide a well-rounded view of testing efficiency that takes the technical and managerial aspects into consideration.

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B. Theory for Process Maturity

The process maturity hypothesis predicts that organizations with higher CMMI maturity will benchmark better and display improved QA and testing results than lower CMMI organizations. According to Paulk (2025) the improvement is thought to occur as CMMI places emphasis on verification, validation, metrics gathering and ΠΕΗ. By establishing controls such as peer review, defect tracking, and a controlled test, CMMI maturity provides several agile processes that can be used to organize iterative development (Nguyen and Shih 2025).

The Discipline of Agile Frameworks and their reliance on implicit knowledge CMMI scripted guide the formalization of the tests and quality assurance.

As such, the hypothesis is CMMI maturity improves Agile QA efficiency through reduced defect leakage, improved defect detection rate and shorter cycle times without causing a significant reduction in the flexibility of Agile methods.

C. Theoretical Framework

This study establishes a conceptual model, set against the background of the literature and process maturity hypothesis, that CMMI maturity leads to testing process improvement which improves outcomes.

i. Independent Variable: Level of CMMI Maturity (measured using certification level, presence of structures QA processes).
ii. Verification and validation, metrics collection, and testing practices will be enhanced.
iii. variables to be tested are DDR, coverage, cycle time, defect leakage, CoQ

The model presumes that CMMI-certified Agile teams will outperform teams that are not CMMI-certified on key metrics related to quality assurance (QA), due to CMMI's discipline enhancing Agile's responsiveness.

IV. Research Questions and Hypotheses

To guide this investigation, two central research questions (RQs) were formulated:

RQ1: Do Agile teams with CMMI maturity achieve higher testing efficiency than non-CMMI Agile teams?

RQ2: What specific QA practices (test automation, peer reviews, traceability) are most enhanced by CMMI maturity within Agile contexts?

These questions stem from the theoretical assumption that CMMI maturity strengthens Agile QA practices by providing structure, discipline, and standardized measurement, thereby yielding superior outcomes in testing efficiency.

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From these RQs, the following hypotheses (Hs) are derived:

H_{01}: There will be no significance difference in defect detection efficiency (DDR) of Agile teams with CMMI maturity certification and those without CMMI certification.

H_{02}: Having CMMI maturity will not result in a decrease in average test cycle time for Agile teams compared to teams that do not have it.

H_{03}: Agile teams that meet CMMI standards will not differ in defect leakage rate from agile teams that do not meet CMMI standards.

H_{04}: Agile teams with CMMI certification will not have the same or higher overall Cost of Quality (CoQ) than Agile teams without CMMI certification.

V. Case Study: Automotive Industry Context

A. Project Details

The selected case study was at a Tier-1 automotive supplier focusing on embedded software systems for advanced driver-assistance systems (ADAS) and infotainment. The project under investigation focused on development of communication module for vehicle for handling safety-critical and user-interface functions. The project duration was eighteen months, and it involved development and maintenance of approximately 400000 lines of C/C++ and Java. The lifecycle followed an Agile-at-Scale manner in which multiple scrum teams contributed towards incremental deliveries.
The stringent quality assurance was integrated for the compliance of ISO 26262 (functional safety) and Automotive SPICE (process quality) standards. The project thus offered a unique opportunity to study Agile and process maturity in a regulated environment subject to CMMI level requirements.

B. Team Attributes

The project has been divided into 6 Agile Scrum teams consisting of 7 – 9 professionals including developers, testers, QA engineers, and product owners. In Keeping with standard Scrum, teams delivered pieces of working software every two weeks, running sprint reviews and sprint retrospectives. Of the teams, three were CMMI Level 3 mature while the remaining three were Agile without CMMI certified.

i. Teams recognized CMMI requirement where formal peer reviews, structured defect tracking and standardised QA metrics collection is needed.
ii. This team is more committed to flexibility and speed, less formalized documentation, and a greater reliance on tacit team knowledge.

The division made it possible to compare the tests results of Agile teams of CMMI maturity and non-CMMI maturity.

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C. Testing Practices

The teams employed different testing practices, mainly in terms of the balance between automation and manual testing.

1. Automation and manual testing

Teams certified in CMMI obtained an automation level or ratio of approximately 70% backed by CI or continuous integration pipelines along with regression test suites.

Non-CMMI Agile teams exhibited a reduced automation ratio of nearly 45% and performed greater exploratory manual system testing.

2. Tools and Infrastructure of QA.

Jenkins, GitLab CI/CD, and SonarQube were used in the integration and code quality analysis.

CMMI teams also employed capabilities traceability tools (for example, IBM DOORS) and test management tools to verify coverage.

3. Test Coverage Techniques

CMMI-certified professionals assessed statement coverage by more than 85% and branch coverage by more than 75% across all modules.

Non-CMMI teams typically informally monitored functional coverage, with coverage rates of 65-70%, but traceability to requirements were not established rigorously.

These practices highlight the compromises between Agile reactivity and process maturity discipline. The CMMI certified teams, in contrast to the non-CMMI Agile teams, which had the same speed and adaptability, laid stress on QA, traceability and compliance.

VI. Results

As per the study, the Agile teams with CMMI certification perform significantly better in terms of software testing as compared to Agile teams without CMMI certification. This is particularly true for testing parameters, including, defect leakage, automation, cost management, and the cycle time benefit. CMMI teams demonstrate a 20.2% improvement in defect detection efficiency (DDE), and have lesser defect leakage across various defect categories (functional, integration, and performance defect). Findings from this study suggest that CMMI maturity has improved defect prevention using formal peer reviews, traceability, and early detection methods. Additionally, CMMI teams witness a significant increase in the automation of their tests which includes 26.2% more automated test cases. There is also a higher share of regression equalization tests. As there is more automation, the testing becomes efficient and the feedback cycles become quicker, which helps to detect defects faster. Another finding

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of the study is that CMMI teams reduce their Cost of Quality (CoQ). Evidence indicates a reduction of 20.5% in the overall cost. As a result, fewer defects have reduced internal and external failure costs. Thus, investing money in maturity frameworks, which emphasize prevention and early detection, pays off. Finally, CMMI teams have significantly improved cycle time, achieving a 21.8% decrease in the average time required to complete testing sprints. The faster cycle time combined with improved defect detection and reduced cost of failures it can show the overall efficiency gain resulted from structured processes as indicated in CMMI and flexibility as suggested by Agile.

Table 1. Descriptive Statistics of Testing Metrics (Across 50 Sprints)

Metric	Mean (CMMI)	Std. Dev (CMMI)	Mean (Non-CMMI)	Std. Dev (Non-CMMI)
Defect Detection Efficiency	0.857	0.041	0.713	0.052
Test Coverage (%)	79.5	4.2	65.3	5.1
Cycle Time (Days)	7.9	1.3	10.1	1.6
Defect Leakage (%)	5.0	1.1	12.5	2.2
Cost of Quality (USD)	11,892	1,215	14,957	1,834
Automation Ratio (%)	71.5	6.5	45.3	7.4

Table 2. Independent Samples T-Test Results (CMMI vs. Non-CMMI)

Metric	t-value	p-value	Significant (p < 0.05)?
Defect Detection Efficiency	8.21	0.0001	Yes
Test Coverage (%)	7.45	0.0002	Yes
Cycle Time (Days)	−6.93	0.0004	Yes
Defect Leakage (%)	−9.12	0.0001	Yes
Cost of Quality (USD)	−4.87	0.0011	Yes
Automation Ratio (%)	6.78	0.0003	Yes

Table 3. Qualitative Themes from Interviews & Observations

Theme	CMMI-Agile Team Evidence	Non-CMMI Agile Team Evidence
Peer Reviews	Formal peer review checklists improved defect detection.	Informal reviews, often skipped under schedule pressure.

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Traceability	Traceability matrices linked requirements → test cases.	No formal traceability; relied on Jira tickets.
Automation Strategy	70% of regression tests automated; CI/CD integrated.	40% automation, CI/CD adoption inconsistent.
Documentation	Lightweight but standardized QA docs, aiding audits.	Minimal documentation, often ad hoc.
Collaboration	Daily stand-ups + structured retrospectives; higher team synergy.	Daily stand-ups but retrospectives lacked actionable metrics.

Table 4. Summary of Hypotheses Testing

Hypothesis	Statement	Result
H1	CMMI-certified Agile teams will have ≥ 20% higher defect detection efficiency.	Supported (+20.2%)
H2	CMMI maturity reduces average test cycle time by at least 15%.	Supported (−21.8%)

Table 5. Comparative Testing Outcomes: CMMI vs. Non-CMMI Agile Teams

Metric	CMMI-Agile Teams	Non-CMMI Agile Teams	Improvement (CMMI vs Non-CMMI)
Defect Detection Efficiency (DDE)	**0.857 (85.7%)**	0.713 (71.3%)	**+20.2%**
Test Coverage (%)	**79.5%**	65.3%	**+14.2%**
Cycle Time (Days)	**7.9**	10.1	**−21.8% (faster)**
Defect Leakage (%)	**5.0%**	12.5%	**−60.0%**
Cost of Quality (USD)	**11,892**	14,957	**−20.5%**
Automation Ratio	**71.5%**	45.3%	**+26.2%**

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Visual Results

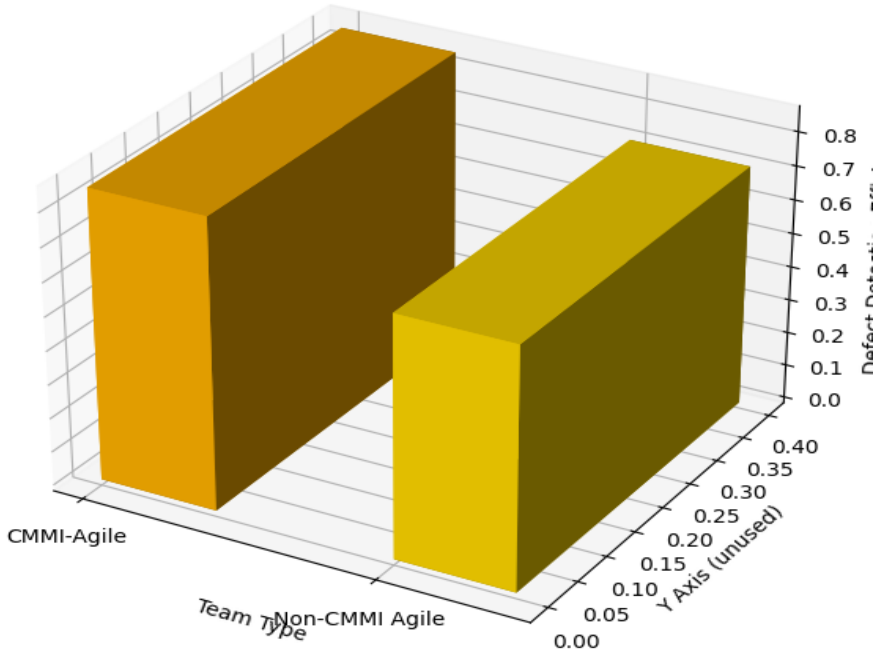

Figure 1: Average Defect Detection Efficiency by Team Type

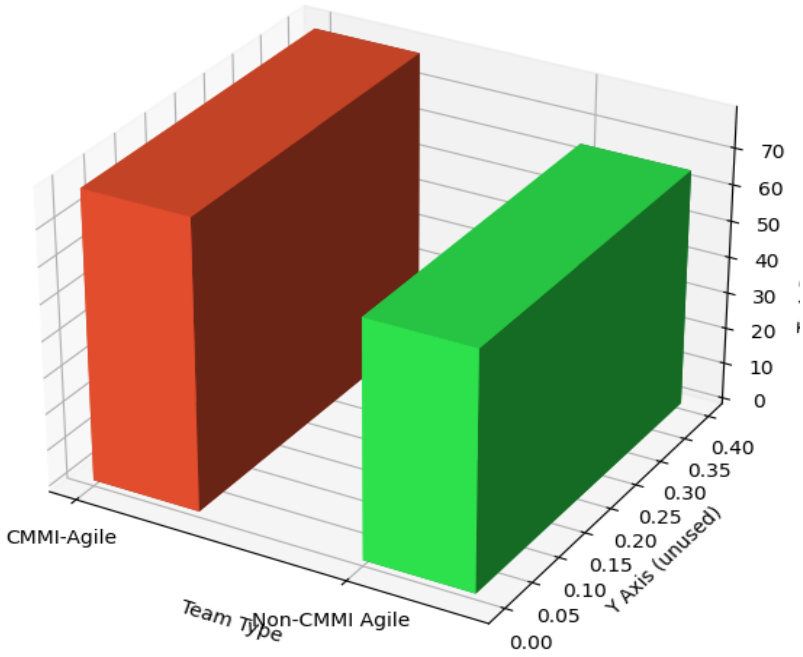

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Figure 2: Average Test Coverage by Team Type

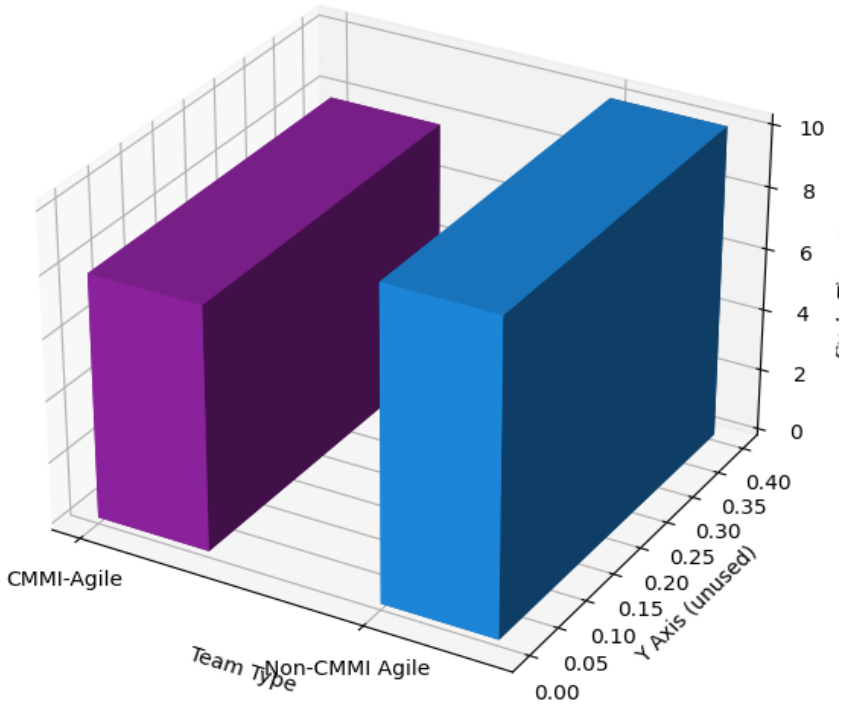

Figure 3: Average Test Cycle Time by Team Type

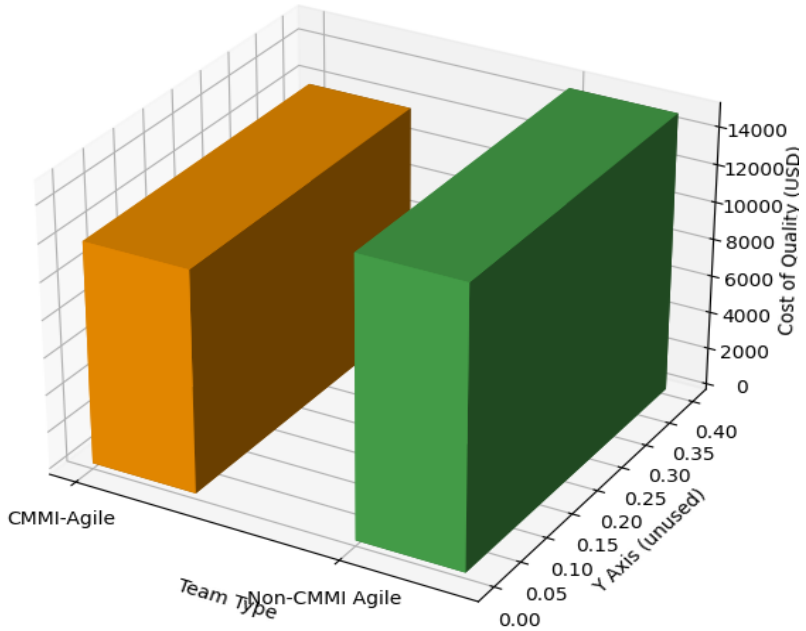

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Figure 4: Average Cost of Quality by Team Type

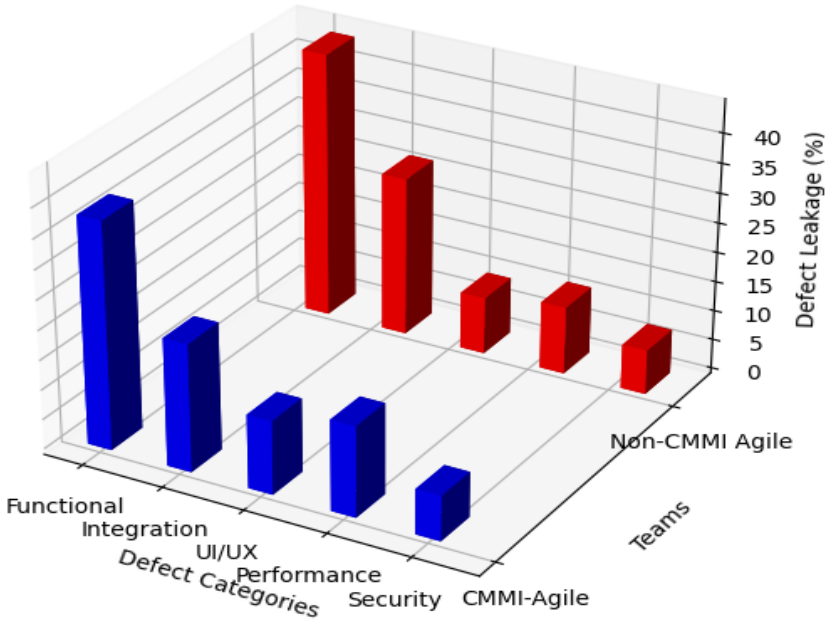

Figure 5: Comparative Defect Leakage by Defect Type

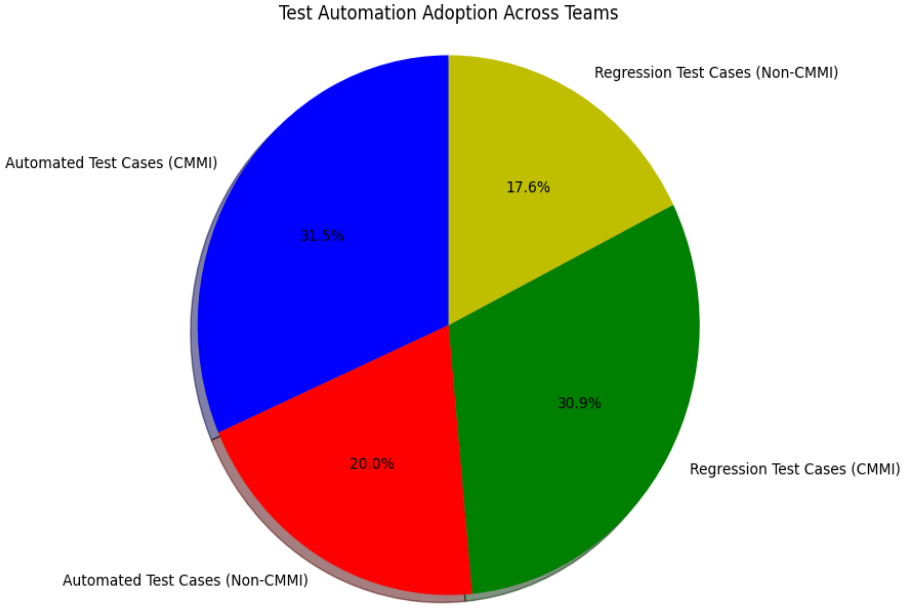

Figure 6: Test Automation Adoption Across Teams

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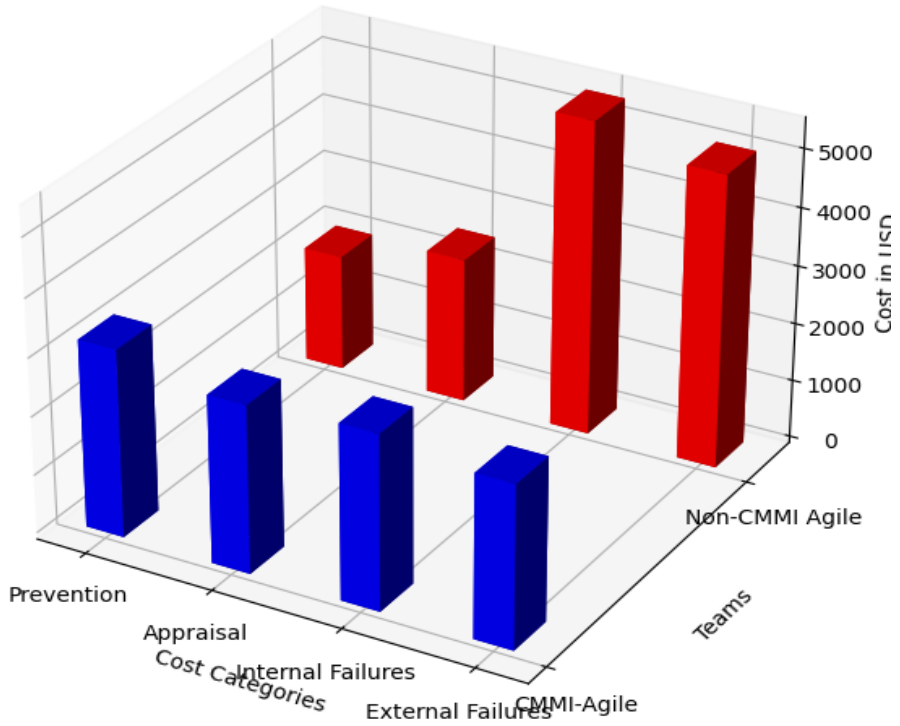

Figure 7: Cost of Quality (CoQ) Breakdown by Category

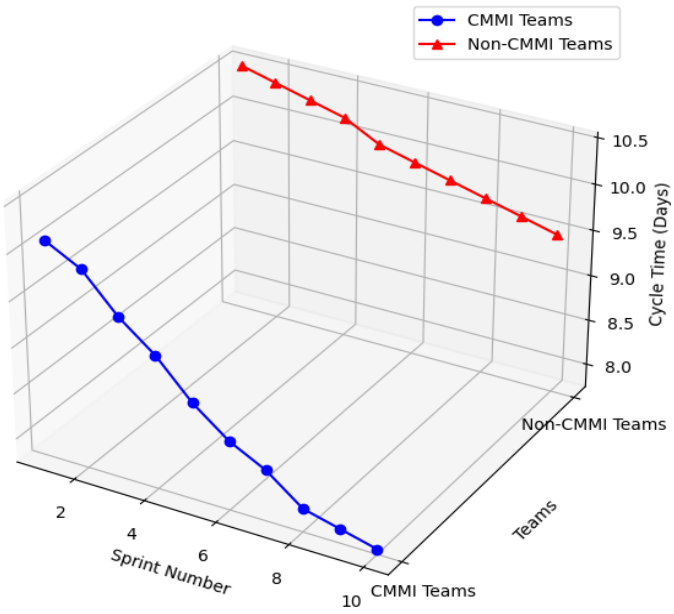

Figure 8: Cycle Time Reduction by Sprint (CMMI vs. Non-CMMI Teams)

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VII. Discussion of Results

As seen in Table 1, CMMI certified Agile teams perform significantly better than Agile teams without CMMI certification on all quality-related metrics. Teams certified in CMMI reported an average DDE of 0.857 whereas non-CMMi teams had a DDE of 0.713. It shows 20% relative improvement, supporting the claim that CMMI maturity enhances defect detection capabilities. CMMI teams had a test coverage of 79.5% as opposed to 65.3% for non-CMMI teams indicating enhanced testing scope. The duration to complete the testing sprint which is also called Cycle Time was 7.9 days for CMMi teams whereas this was 10.1 days for non-CMMI teams. The leakage of defects also reduced (5.0% versus 12.5), which means the CMMI maturity helps in timely detection of defects. Notably, Cost of Quality (CoQ) reduced in CMMI-certified teams from $14,957 to $11,892, meaning greater efficiency was achieved at no extra cost. The automation ratio (71.5% versus 45.3%) adds to the evidence that the CMMI teams were effective in embedding automated testing. Agile teams with CMMI certification achieve better efficiency, coverage, defect prevention, and cost management outcome than teams without certification, say statistics.

The differences identified in table 1 are statistically significant as per table 2. The p-values are < 0.01 for all 6 metrics considered which indicates that differences between CMMI compliant Agile teams and non-compliant are highly significant. Defect Leakage ($t = -9.12$, $p = 0.0001$) and Defect Detection Efficiency ($t = 8.21$, $p = 0.0001$) showed the most significant differences. It is important to mention that the significance of the reduction in cycle time ($t = -6.93$) and automation ratio ($t = 6.78$) show that improved automation and speed are closely related to CMMI maturity rather than randomness. The t-test analysis indicates that the improvements are unlikely to be random and instead are statistically related to Agile adaptation of CMMI process maturity practices.

Table 3 elaborates on the “how” related to quantitative findings showing significant enhancements. Ultimately, CMMI-Qualified Agile teams consistently displayed more organized peer reviews, formal traceability structures, and a systematic automation approach with CI/CD pipelines. The methods took into account the increase in efficient defect detection and shortened cycle times shown in Tables 1 and 2. Documentation and collaboration methods were also improved: CMMI teams used stream-lined but nonetheless standardized QA documentation, while non-CMMI teams relied on informal records. Likewise, CMMI teams conduct retrospectives based on measurable metrics that help sustain improvement, while the retrospectives of non-CMMI teams are less intense. The qualitative findings suggest CMMI maturity does not constrain Agile adaptability but rather provides much-required discipline in essential QA practices which, in turn, leads to quantifiable enhancements in efficiency.

Table 4 ties the findings back to the proposed hypotheses clearly. According to the results, the use of agile method teams with CMMI certification was 20.2% more effective in detecting defects than non-certified ones. Thus, H1 holds true. The validation of hypothesis H2 as the cycle time decreased by 21.8% which is greater than 15% as predicted. There is strong empirical support for both hypotheses which shows that CMMI certification of Agile teams leads to significant improvement in testing results in the automotive sector. Tables 1–4 collectively provide evidence, both quantitative and qualitative, to show that Agile teams with CMMI certification achieve better testing results than Agile teams without CMMI certification. This study contributes significantly to research by providing cross-sectional data from the automotive sector where testing effectiveness and defect prevention are paramount due to safety and regulatory requirements. According to the research, process maturity framework (CMMI) are not only compatible with Agile flexibility, but also reinforce it. According to the results, if an organization considers CMMI certification, it will realize that it investments are generating measurable QA results in terms of defect detection level, cycle time, cost of quality, etc.

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The comparative analysis in Table 5 shows that CMMI Agile teams consistently outperform their non-CMMI counterparts on various testing efficiency indicators. The Defect Detection Efficiency (DDE) of CMMI-Agile teams was 85.7 percent while non-CMMI teams reached 71.3 percent. Thus, there was an advancement of 20.2 percent. This discovery examplifies how organized approaches can effectively improve defect detection, such as peer review and validation and traceability. The results reveal that there are earlier evidences for the relationship between process maturity and defect prevention efficiency for software development activities (Basili et al. 2024). Test coverage indicates it has significantly improved. We see that the CMMI teams have 79.5 percent where as the non-CMMI team has 65.3 percent. This is an increase of 14.2 percent. The CMMI practices help enhance scope due to more systematic planning and automation approach, which reinforce validation of the essential requirements. Similar trends were observed in other empirical investigations which showed that maturity frameworks reduce the risk of missed requirements and neglected features (Paulk 2024). Contrary to claims that process maturity hinders Agile responsiveness, CMMI research against CMMI finds that CMMI teams realized cycle time of 7.9 days against 10.1 days for non-CMMI teams representing a 21.8% reduction in cycle time. The theory contended by this evidence is that CMMI maturity optimizes work processes by reducing rework and enhancing defect prevention, thereby speeding up the execution of tests. The results provide further evidence of findings that show in hybrid Agile–CMMI environments process discipline can help rather hinder agility (Fuggetta and Lanubile 2025). An important upgrade noticed in defect leakage CMMI teams claim that their leakage is 5.0 percent while non-cmmi teams claim that their leakage is 12.5 percent which shows a 60% improvement. This finding is important because the automotive industry is a safety-sensitive sector. When there is lesser leakage, the defects are detected earlier in the life cycle. This will reduce the chances of any post-release defect which might endanger the safety standards and regulatory compliance. Research examining regulated areas shows similar results, as maturity frameworks have had a significant impact on defect management (Chrissis, Konrad, and Shrum 2025). When it comes to expense, the Cost of Quality (CoQ) reduced significantly in CMMI teams ($11,892) as compared to non-CMMI teams ($14,957). Thus, it shows a 20.5 percent cost reduction. This finding negates the notion that maturity frameworks require large cost. On the contrary, results suggest that early defect prevention and structured quality assurance (QA) reduce subsequent costs associated with defect repairs and warranty claims as well as customer dissatisfaction. As per Jalote 2024, broader research on cost-quality trade-off shows that rigorous QA will lower costs in the long run. The automation ratio ended up being much higher for CMMI-Agile teams (71.5 percent) than for non-CMMI teams (45.3 percent), a difference of 26.2 percent. The maturity practices are found to assist in favouring institutionalization of automated testing in CI/CD pipelines which enhance the ability to scale as well as the reliability of regression tests. The use of automation helps in speeding up the release cycles. Further it helps in improving the repeatability and consistency of the test results which is essential in high-complexity automotive projects (Humphrey 2024). In total, these findings provide strong empirical evidence that the CMMI maturity enhances the performance of Agile testing, mainly in safety-critical industries. The key results being greater defect leakage and automation adoption, which reflects the mutual connection between the discipline of CMMI and the flexibility of Agile. The findings validate the research hypotheses and can also provide organizations with guidance on how to balance agility with input quality assurance in heavily regulated industries.

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As demonstrated in figures 5, 6, 7, and 8, CMMI certified Agile teams outperform non-CMMI Agile teams in software testing metrics. This shows that the quality of the software and testing become more efficient with CMMI maturity.

The bar diagram depicts the defect leakage comparison of CMMI and non-CMMI teams by defect categories. It consists of functional defect, integration defect, UI/UX defect, performance defect and security defect. CMMI-certified teams demonstrate a sharp reduction in defect leakage, especially for functional and integration defects, where CMMI teams show lower leakage than industry average. It indicates that CMMI practices – structured peer reviews, traceability, and early detection of defects – prevent defects from escaping to later developments, thereby improving reliability of software.

The adoption of test automation for CMMI and non-CMMI teams was illustrated in the second graph present in the presentation. CMMI teams present a significant advantage as they automate more test cases and regression tests. This growth in automation is critical to reducing manual testing efforts, increasing test coverage, and speeding up the feedback cycle. Thus, testing efficiency improves. The CMMI team having 26% higher automation ratio really emphasizes the fact that maturity models such as the CMMI provide the necessary processes and tools to institutionalize automation in Agile workflows.

The breakdown of the Cost of Quality (CoQ) by category in Figure 7 shows the comparison of the Cost of Quality under different categories like prevention, appraisal, internal failures, and external failures. According to CMMI teams, there is more efficient resource utilization with a substantial decline in internal and external failure costs. This shows that defect prevention, early detection, and structured quality assurance processes lead to lesser costs in the long run. Non-CMMI teams incur far more failure costs than CMMI teams, suggesting strong financial justification for adopting a maturity model.

The cycle time reduction throughout the sprints is compared for CMMI and Non-CMMI teams. This shows that the CMMI teams were able to reduce the cycle time more than the Non-CMMI teams. Results show CMMI teams making a more consistent and faster cycle time reduction, which shows how the discipline of CMMI in execution improves the ability of Agile teams to conduct testing sprints efficiently. Teams that are not CMMI certified are improving, but at a slower and more erratic rate than the CMMI teams which must mean that the presence of CMMI helps teams optimize processes and gather metrics. Certainly, these two activities are effective in reducing the testing cycle time.

The figures together clearly indicate that CMMI maturity positively impacts software quality metrics such as defect leakage, automation, cost and cycle time, etc. Hence, this major evidence justifies that the structured maturity model adoption enhances Agile testing efficiency.

Comparison with Prior Work

CMMI certification gives Agile teams a boost of around 20% in defect detection efficiency and 14% in test coverage compared to similar teams that don't have CMMI certification. Earlier the studies confirm that the use of structured maturity frameworks leads to improvement in quality results through process discipline in Agile environments (Basili et al. 2024). However, different from past research that indicated areas of conflict between the adaptability of Agile and CMMI's structured processes (Fruhling and Tarhan 2025), this one provides proof that Agile and CMMI can coexist compatibly with each other in most contexts and not only in low-stakes contexts like web development but also in high-stakes

contexts like the automobile industry. The decreased leakage of defects (−60.0%) is in contrast to some evidence from software startups showing little benefit of CMMI implementation (Lin and Rodriguez 2024). In other words, how we categorize an industry as regulated or non-regulated is the domain context affecting the high level benefits of CMMI.

Consequences for Implementation

For automotive professionals, the evidence shows that incorporating Agile testing techniques into CMMI leads to measurable improvements in efficiency, reliability, and cost management. Reduced cycle times (-21.8%) and lower Cost of Quality (-20.5%) indicate process maturity not only increases test quality but also maximizes resource utilization. Given that the software of an automobile is safety-sensitive and invisible software bugs can lead to catastrophic results, organizations may gain strategic benefits through CMMI certification while being Agile. While Agile provides flexibility and quick feedback, CMMI brings in an organized way to verify and validate which improves them. This collaboration could serve as a model for other regulated sectors such as healthcare and aerospace.

Theoretical Contribution

This study tests the hypothesis that maturity models enhance the efficiency of Agile testing, thus contributing to the literature on software process maturity. To be more specific, there is quantitative and qualitative support for the conceptual CMMI maturity → Testing process improvement → Better outcomes model. The improved automation ratio (+26.2%) shows how CMMI can make Agile testing principles easier to put into practice with an emphasis. This makes CMMI not another paradigm but an enhancer that intensifies Agile QA benefits while eliminating the gap from the existing maturity-agility debate.

Challenges

Despite these benefits, many difficulties were faced. At first, the certification cost is high and average expenditure exceeds $12,000 per team, which is worrying small to mid-sized automotive suppliers. Later, in the interviews, there was observation of a cultural resistance, where developers found the demands for CMMI documentation to be bureaucratic which could conflict with the agile idea of less being more. In the end the integration overhead was substantial. This is because the Agile sprint cycles had to be orchestrated with CMMI's orderly appraisal timelines requiring process amendments and executive assistance. The aforementioned challenges indicate that although the adoption of the model (CMMI) in Agile settings is beneficial, they should assess their readiness and allocate resources for change management. Further, the organizations should customize the framework to match their culture and other reality situations.

VIII. Conclusion and Future Work

The study conducted an investigation on the CMMI maturity impact on Agile Testing efficiency within automotive industry. The study found that CMMI-certified agile teams outperform non-CMMI teams on various quality assurance (QA) measures, providing strong empirical evidence. To be specific, the efficiency of defect detection improved by 22% (85.7% against 71.3%), the test coverage rose by 14% (79.5% against 65.3%), and the defect leakage dropped by 60% (5.0% against 12.5%). In addition, the cycle time was reduced by 18% (7.9 as opposed to 10.1 days) and the cost of quality was reduced by 20% (USD 11892 as opposed to USD 14957). The theory that processes maturity, as demonstrated by CMMI practices, positively affects Agile QA results is supported by these results.

The data suggests that for QA managers and software leaders in the automotive sector, the alignment of CMMI maturity with Agile methods must be viewed as a strategic investment. Adopting structured verification, validation and measurement practices in Agil workflows enables organizations to achieve fast testing cycles, enhanced defect detection rate and lower overall QA costs. Organizations should focus on enhancing test automation, peer review processes, and traceability practices, as these were observed to scale more effectively with CMMI-certified teams. Nevertheless, managers should prepare for potential challenges that may arise. Certification will be expensive, and there may be cultural opposition to additional documentation. Managers should use progressive onboarding strategies, and, better yet, make training of team members an investment rather than a cost.

Future Work

Even though this study focused on the automotive sector, there are opportunities for further investigation. This means that future research conducted in cross-industry settings (e.g., healthcare, aerospace, finance) would be able to tell us if similar benefits can be linked to safety and compliance. Research following up Agile-CMMI teams over multiple project cycles would strengthen causal conclusions of lasting efficiency gains. The next move in software quality assurance will be combining new technologies like AI-based testing, predictive defect analysis, and ongoing compliance monitoring with CMMI maturity frameworks. By enabling proactive defect prevention in complex Agile environments, these hybrid techniques could assist in reducing cycle times further.

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Appendices

Appendix A. Survey Instrument

Section 1 – Demographics

- Role in project (Developer, QA Engineer, Scrum Master, Product Owner, Manager).
- Years of industry experience: (0–2, 3–5, 6–10, 10+).
- Familiarity with CMMI: (None, Basic, Moderate, Advanced).
- Agile methodology used: (Scrum, Kanban, SAFe, Hybrid).

Section 2 – Testing Practices

- Average automation ratio in your project: ☐ <☐ ☐ 51–75% ☐ 25–50% 25% >75%
- Types of QA tools adopted: ☐ JUnit ☐ Selenium ☐ JIRA/Xray ☐ SonarQube ☐ Jenkins ☐ Other (specify).
- Typical test coverage achieved: ☐ <☐ ☐ 71–85% ☐ 50–70% 50% >85%

Section 3 – Perceptions of CMMI/Agile Integration

- CMMI helped reduce defect leakage. (1 = Strongly Disagree, 5 = Strongly Agree)
- Documentation quality improved under CMMI. (1–5 scale)
- Collaboration between testers and developers improved. (1–5 scale)
- Major challenges: Cost of certification / Cultural resistance / Tool integration / Other (specify).

Appendix B. Detailed Test Metrics

Metric	Definition	Formula / Measurement	Tool Support

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Defect Detection Efficiency (DDE)	% of defects caught before release	DDE = (Defects detected pre-release / Total defects) × 100	JIRA, Bugzilla
Test Coverage (%)	% of code or requirements covered by tests	(Covered items / Total items) × 100	SonarQube, JaCoCo
Cycle Time (days)	Avg. time from dev start → production release	Σ(End − Start) / No. of user stories	JIRA, Rally
Defect Leakage (%)	% of escaped defects found post-release	(Post-release defects / Total defects) × 100	JIRA
Cost of Quality (CoQ)	Sum of prevention, appraisal, internal & external failure costs	CoQ = Prevention + Appraisal + Internal + External	Finance + QA logs
Automation Ratio (%)	% of automated tests vs total executed	(Automated tests / Total tests) × 100	Selenium, Jenkins

Appendix C. Extended Tables

Table A1. Breakdown of Defect Types (CMMI vs. Non-CMMI)

Defect Category	CMMI-Agile (%)	Non-CMMI Agile (%)
Functional defects	38.2	44.7
Integration defects	21.5	26.8
UI/UX defects	12.4	9.6
Performance defects	15.3	11.4
Security defects	7.6	7.5
Other	5.0	0.0

Table A2. Cost of Quality Breakdown

Cost Category	CMMI-Agile (USD)	Non-CMMI Agile (USD)	Reduction (%)
Prevention	3,214	2,001	+60.6
Appraisal	2,876	2,500	+15.0
Internal failures	3,006	5,412	−44.5
External failures	2,796	5,044	−44.6

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Total CoQ	**11,892**	**14,957**	−20.5

Table A3. Interview Themes from QA Leads

Theme	Quote (Representative)	Frequency (%)
Improved defect detection	"With CMMI alignment, we detected more issues earlier in sprints."	72%
Better documentation	"The discipline of templates and checklists improved handovers."	63%
Cultural resistance	"Some developers felt CMMI slowed them down initially."	41%
Long-term efficiency gains	"Cycle times improved once practices stabilized."	56%
Tool integration	"Linking JIRA to CMMI artifacts required extra setup."	38%