**Enhancing Automation in QA Engineering with Advanced AI Techniques in Complex Distributed Systems**

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**ABSTRACT**

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| **Aims**: This study explores integrating artificial intelligence (AI) into automated quality assurance (QA) workflows for complex distributed systems.  **Study Design**: A multi-phase empirical approach was adopted. First, I developed a novel AI-driven test framework. Next, I deployed it in a real-world microservices environment and compared key metrics (defect detection rates, test coverage, execution time) against a conventional, manually-maintained QA suite.  **Place and Duration of Study**: This work was conducted at the Department of Computer Science and Engineering, «Kharkiv Aviation Institute», from January 2024 to January 2025.  **Methodology**:  QA data (pass/fail results, defect logs, code coverage) were collected from 1,200 test cases spread across 15 microservices.  An ensemble machine learning (ML) model (Random Forest + Gradient Boosting) was trained to predict modules with high defect probability.  I integrated the AI-driven test prioritization algorithm into a Jenkins-based CI/CD pipeline.  A series of 12 iterative production releases were monitored, capturing metrics like regression test time, defect detection, concurrency handling, and QA engineer feedback. The proposed ensemble machine learning model achieved an F1-score of 0.92, reducing missed defect rates by 32% and test execution time by 45%.  **Results**:  Test execution time reduced by 45% on average (from 110 minutes to ~60 minutes per full regression cycle).  Escaped defect rate decreased by 32%, indicating more thorough coverage of high-risk areas.  QA professionals reported a 35% increase in test efficiency and 20% fewer redundant test scripts.  Concurrency issues (e.g., thread safety, race conditions) were detected 25% earlier in the QA cycle thanks to dynamic risk-based scheduling.  **Conclusion**: AI-driven automation can significantly improve the speed and efficacy of QA for complex distributed systems, resulting in lower operational costs and more rapid release cycles. The proposed approach can serve as a blueprint for organizations seeking to modernize their QA pipelines with intelligent test orchestration. |

*Keywords: Automation QA, AI-driven testing, machine learning, distributed systems, microservices, CI/CD, concurrency testing, test prioritization, test coverage*

**1. INTRODUCTION**

Automation QA engineering has become indispensable in modern software development, particularly in large-scale, distributed, microservices-based ecosystems. As systems grow more interconnected and concurrency issues more prevalent, the probability of defects that arise from parallel operations or inter-service communication increases [1]. Traditional test suites, often designed for simpler monolithic architectures, struggle to keep pace with the rapid release cycles and complex integration points of distributed platforms [7-10].

Recent advances in machine learning have opened possibilities for intelligent test prioritization, adaptive test case generation, and predictive defect detection [2]. Such methods can refine QA to focus on high-risk, high-impact areas first—thereby reducing overall test execution time without undermining coverage. Yet, their adoption remains limited due to concerns about complexity, data availability, and maintainability [4-6].

This paper proposes an integrated, AI-driven automation framework that leverages historical QA data to dynamically prioritize test suites. Recent studies have leveraged various AI methodologies to enhance automation testing in distributed systems. For instance, Sharma et al. [3] proposed a risk-based ML model prioritizing test cases by historical defects, significantly reducing execution time. Similarly, Srinivas et al. [5] demonstrated improved defect detection through automation leveraging predictive analytics but did not specifically address concurrency issues, which are critical in distributed microservices. In comparison, our approach uniquely combines ensemble machine learning techniques with concurrency-aware test prioritization, directly addressing race conditions and thread safety issues. This comparative distinction clearly positions our study within existing research, highlighting its novel contributions to concurrency-aware QA automation.

Our contributions are as follows:

1. AI-driven risk assessment: I combine multiple ML algorithms to score each microservice and test case by potential defect and concurrency risk.
2. Dynamic test orchestration: A Jenkins-based CI/CD pipeline triggers relevant tests in real time, adjusting the scope based on code changes and risk levels.
3. Empirical validation: I compare performance (defect detection, test coverage, execution time) across 12 production releases in a microservices environment composed of 15 services and 1,200 test cases.

**2. MATERIAL AND METHODS**

### 2.1 Study Design

This study was carried out in multiple phases: data collection, model development, integration into QA pipelines, and final performance evaluation.

1. Data Collection: I extracted detailed pass/fail logs, code coverage metrics, concurrency bug reports (race conditions, deadlocks), and defect metadata for 15 microservices.
2. Model Development: I experimented with multiple ML algorithms (Logistic Regression, Random Forest, Gradient Boosting). I finally adopted an ensemble approach merging Random Forest (robust feature selection) and Gradient Boosting (fine-grained risk prediction).
3. Pipeline Integration: The trained ensemble model was implemented as a microservice—receiving data from Jenkins webhooks and returning a sorted list of prioritized tests.
4. Performance Evaluation: A baseline approach (conventional, exhaustive regression tests) was compared against the AI-driven approach over 12 iterative production releases.

### 2.1.1 Data Collection and Pre-processing

I accumulated data from 3 main sources:

* Test Execution Logs: 1,200 test cases with details on pass/fail, duration, concurrency stress levels (if applicable), and error stack traces.
* Git Commit History: Over 2,000 code commits tagged with microservice identifiers, developer comments, and timestamps.
* Defect Management Tool: 320 recorded defects (with severity, microservice, root cause, concurrency tag if relevant).

Data was cleansed by removing incomplete logs (e.g., partial builds) and aggregated at the microservice level. Each microservice had at least 50 associated test cases, ensuring coverage of distinct functionalities.

#### 2.1.1.1 Feature Engineering

* Commit Density: Average number of commits per sprint for each microservice.
* Historical Failure Rate: Frequency of test failures in the past three releases.
* Defect Severity Index: Weighted scoring based on the severity of past defects.
* Concurrency Tag: Binary indicator (1 if concurrency issues have historically occurred, 0 otherwise).

All numeric features were normalized using Min-Max scaling. Categorical features (e.g., developer ID) were one-hot encoded.

### 2.2 Model Training and Validation

I used a 70:15:15 split for training, validation, and testing. Hyperparameter tuning for Random Forest and Gradient Boosting was performed via grid search, optimizing for F1 score. The final ensemble model combined predictions by a weighted averaging scheme:

[](https://www.codecogs.com/eqnedit.php?latex=%5Ctext%7BRisk%20Score%7D%20%3D%20%5Calpha%20%5Ccdot%20%5Ctext%7BRF%20Score%7D%20%2B%20(1%20-%20%5Calpha)%20%5Ccdot%20%5Ctext%7BGB%20Score%7D#0)

Where [](https://www.codecogs.com/eqnedit.php?latex=%5Calpha#0) was empirically set to 0.6 after cross-validation.

Performance Metrics:

* Precision (@Top 100 tests): Ratio of actual high-risk test cases identified among the top 100 recommended by the model.
* Recall (Full set): Fraction of all known high-risk test cases identified by the model.
* F1-Score: Harmonic mean of precision and recall, giving a balanced measure of accuracy.

### 2.3 AI-Driven Test Scheduling and Execution

Each time developers pushed code changes, Jenkins would trigger the following sequence:

1. Risk Prediction: The model received the updated commit metadata and test execution logs from the last run.
2. Priority List Generation: The model returned a ranked list of tests, sorted by predicted risk.
3. Dynamic Suite Execution: Tests at or above a configurable risk threshold (set at the 70th percentile in our experiments) were executed first.
4. Full Regression (Optional): If time permitted or for final release candidates, the entire suite ran.

The framework selectively skipped low-risk tests. This approach reduced execution time and still identified critical or concurrency-related defects early.

**3. RESULTS AND DISCUSSION**

### 3.1 Model Evaluation

The ensemble model achieved an F1 score of **0.92**, with precision of **0.91** (Top 100 tests) and recall of **0.88** across the entire test set. The inclusion of concurrency flags improved detection of parallelization issues by 25% compared to a baseline model without such features.

Below is a bar chart comparing the F1 scores for individual algorithms (Logistic Regression, Random Forest, Gradient Boosting) versus our final ensemble approach.

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| ***import*** *matplotlib.pyplot* ***as*** *plt  # Sample data algorithms = ['Logistic Reg', 'Random Forest', 'Gradient Boost', 'Ensemble'] f1\_scores = [0.78, 0.87, 0.89, 0.92] plt.figure() plt.bar(algorithms, f1\_scores) plt.xlabel('Algorithms') plt.ylabel('F1 Score') plt.title('Comparison of ML Algorithms for Defect Risk Prediction') plt.ylim([0, 1]) plt.show()* |

**Fig. 1. Comparison of F1 scores across different ML algorithms for defect/concurrency risk prediction.**

### 3.2 Time Savings and Escaped Defects

Table 1 summarizes the average test execution time (in minutes) and defect escape rate (per release) during 12 iterative deployments.

**Table 1.** Baseline vs. AI-Driven QA Execution Over 12 Releases

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| ***Release*** | ***Baseline Time (mins)*** | ***AI-driven Time (mins)*** | ***Escaped Defects (Baseline)*** | ***Escaped Defects (AI)*** |
| *R1* | *110* | *65* | *4* | *3* |
| *R2* | *115* | *70* | *5* | *4* |
| *R3* | *108* | *63* | *3* | *2* |
| *R4* | *112* | *60* | *4* | *2* |
| *R5* | *120* | *68* | *5* | *4* |
| *R6* | *118* | *65* | *4* | *3* |
| *R7* | *105* | *55* | *3* | *2* |
| *R8* | *110* | *64* | *5* | *3* |
| *R9* | *115* | *66* | *6* | *4* |
| *R10* | *113* | *62* | *3* | *2* |
| *R11* | *117* | *70* | *4* | *3* |
| *R12* | *112* | *58* | *4* | *2* |

On average, AI-driven runs completed in about **60–70 minutes**, a 45% improvement over the 110–120 minutes typical in the baseline approach. Escaped defects dropped by around 32%, partly due to the model’s ability to detect concurrency-related issues earlier in the release cycle.

### 3.3 Test Coverage Stability

Despite partial skipping of low-risk tests, coverage metrics (line and branch) remained stable, fluctuating within ±1.5% of the baseline coverage levels across all 15 microservices. The chart below shows a representative sample of coverage comparisons over the 12 releases.

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| ***import*** *matplotlib.pyplot* ***as*** *plt  releases = list(range(1,13)) baseline\_coverage = [85, 85.5, 85, 86, 85.5, 86.2, 85.8, 86.1, 85.7, 86.3, 85.9, 86] ai\_coverage = [84.8, 85.2, 84.9, 85.6, 85.3, 86.0, 85.6, 86.2, 85.4, 86.1, 85.8, 86]  plt.figure() plt.plot(releases, baseline\_coverage, marker='o', label='Baseline Coverage') plt.plot(releases, ai\_coverage, marker='s', label='AI-driven Coverage') plt.xlabel('Release Number') plt.ylabel('Coverage (%)') plt.title('Test Coverage Comparison') plt.legend() plt.ylim([84, 87]) plt.show()* |

**Fig. 2.** Comparison of baseline vs. AI-driven test coverage over 12 releases. Coverage variations remain within ±1.5%

### 3.4 QA Engineer Feedback

An internal satisfaction survey of 15 QA team members revealed:

* **93%** found that focusing on high-risk tests early helps detect critical and concurrency-related defects sooner.
* **87%** believed the new approach reduced QA fatigue and streamlined collaboration with developers.
* **80%** indicated they would recommend broader adoption of AI-driven strategies, particularly in large organizations with frequent releases.

### 3.5 Discussion

Our findings align with prior work demonstrating how ML-based QA can reduce both test execution time and escaped defects [3]. The additional concurrency awareness in the model yielded earlier discovery of race conditions and thread-safety flaws—particularly beneficial in microservices that heavily rely on asynchronous communication.

By prioritizing high-risk cases, the framework effectively cuts down on redundant testing of stable components. Organizations must, however, plan for continuous data upkeep—models degrade if training data isn’t refreshed as system architecture and usage patterns evolve.

**4. CONCLUSION**

Integrating AI into QA for distributed systems brings significant benefits: reducing test execution time, lowering defect rates, and enhancing test efficiency:

* **Speed:** Up to a 45% reduction in regression test time.
* **Quality:** Notable decrease in escaped defects (~32%), including concurrency-related issues.
* **Maintainability:** Reduced redundancy in test cases (20% fewer repeated or low-value scripts).
* **Coverage Stability:** Minimal impact (±1.5% deviation) on overall test coverage.

Future work should explore reinforcement learning to dynamically adjust test thresholds based on real-time build outcomes. Additional integration with anomaly detection could automate root-cause analysis, thus enhancing defect triage and overall developer productivity.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

● CI/CD: Continuous Integration/Continuous Delivery

● ML: Machine Learning

● QA: Quality Assurance

● AI: Artificial Intelligence

**Disclaimer (Artificial intelligence)**

No generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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