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Data-Driven DevSecOps: Mining Vulnerability Trends from CI Logs to Improve Security Posture Over Time

Nagateja Alugunuri
Principal DevOps Engineer,
Raleigh, NC, USA.
nagateja4224@gmail.com

Abstract

The evolution of DevSecOps marks a transformative shift in integrating security as a continuous and proactive component within the CI/CD pipeline. However, many organizations lack a systematic, empirical method to measure whether their security posture improves over time. This study proposes a data-driven DevSecOps framework that mines vulnerability trends from Continuous Integration (CI) logs using structured parsing, CVE/CWE mapping, and time-series analysis. Using a dataset of ten successive builds integrated with SonarQube and CodeQL, six key metrics were extracted: Mean Time to Remediate (MTTR), Average CVSS Severity, Recurrence Rate, Secure Build Ratio, Unresolved Vulnerabilities, and a synthesized indicator—Cumulative Security Risk Delta. The results demonstrate consistent improvements across all metrics. MTTR decreased from 12 to 5 hours, recurrence dropped from 30% to 13%, and the secure build ratio rose from 10% to 80%. The Risk Delta offered a unified indicator of evolving posture. These findings confirm that CI logs can serve as a rich source of security intelligence, enabling organizations to transition from reactive to adaptive vulnerability management. This framework provides a replicable and scalable approach for real-time, evidence-based security governance in DevSecOps environments.

Keywords

DevSecOps, CI Log Mining, Vulnerability Trends, Software Security Metrics, Cumulative Risk Delta and Secure Build Automation.

1.Introduction

The convergence of security in the DevOps pipeline more popularly known as DevSecOps has gained immense traction as companies see increasing value in integrating security practices across the lifecycle of software development. This shift from the conventional "bolt-on" approach of security places it as an ongoing and anticipatory process instead of an end-phase checkpoint. The key function of DevSecOps is to be able to deliver software quickly with high quality without sacrificing system integrity or organizational security posture.

Recent surveys have emphasized the strategic value of security integration in DevOps processes, particularly where there are constant deployments, continually changing threat profiles, and minimal manual checks [1]. DevSecOps provides a comprehensive approach with automated security testing, policy compliance, and ongoing monitoring so that development teams can shift left and fix vulnerabilities in the early stages of the lifecycle [2]. Success in DevSecOps relies not only on automation and toolchains but also on organizational preparedness, governance models, and cross-team collaboration [3].

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As artificial intelligence makes inroads in software development, researchers are also working on how AI-based solutions can complement DevSecOps practices—supporting predictive vulnerability identification, anomaly monitoring in CI/CD pipelines, and adaptive security controls [4]. While these progressions exist, most prevailing practices still do not have a data-driven, systematic process for mining and processing CI log telemetry, which contains rich information regarding the evolution of vulnerabilities over time. In addition, although security standards and review criteria are being increasingly codified [5], their actual operationalization via CI data is underresearched.

This research seeks to fill that gap with a data-driven DevSecOps framework that systematically extracts vulnerability trends from CI logs for increased situational awareness and better long-term security posture. With this methodology, security decisions are made based on empirical evidence tapped from within the DevOps pipeline itself, which results in more adaptive, measurable, and resilient security practices.

1.1 Research Objectives

1. To extract and classify vulnerability patterns from Continuous Integration (CI) logs using structured parsing techniques and standardized security taxonomies.
2. To analyze and model security trends over time by computing posture metrics such as Mean Time to Remediate (MTTR), vulnerability severity progression, and recurrence frequency.
3. To identify indicators of security posture improvement through time-series analysis and statistical validation of vulnerability trend shifts across CI/CD pipelines.
4. To recommend adaptive and data-driven actions for DevSecOps teams by translating observed vulnerability behaviors and risk metrics into actionable security enhancements within the development workflow.

1.2 Challenges:

- Unstructured and noisy CI/CD logs make it difficult to extract relevant security information for vulnerability analysis [16].
- Difficulty in correlating vulnerabilities with specific code changes or pipeline stages hinders root cause analysis and accountability [17].
- Inconsistent outputs from evolving security tools complicate integration and standardization across the DevSecOps pipeline [17].
- Scalability and real-time processing limitations affect the timely detection and response to security threats across large systems [18].

2. Review of literature

As DevSecOps matures, more recent studies have investigated challenges in implementing it, cultural considerations, automation plans, and measurement methods. Each study provides individual insights but also indicates significant limitations that together reveal gaps in existing knowledge especially when it comes to real-time, data-driven security monitoring. [6] focused on integrating security into the heart of DevOps by redefining roles and workflows. Though thought-provoking, the research is limited due to its context-bound

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nature, being a master's thesis on one organization without empirical validation or generalization, hence its limit in applicability in various industrial environments. [7] developed ADOC, a theoretical model of ongoing security via open-source automation in cloud ecosystems. The theory of the framework is based on connecting DevSecOps with cloud-native pipelines, but it is theoretical, with no empirical proof or deployment outcomes in the real world indicating its usefulness under dynamic CI/CD environments. [8] searched grey literature to explore applied DevSecOps practice trends and concluded that companies tend to struggle with tool silos and strategic visions. The use of non-peer-reviewed material, however, constrains academic rigour and analysis depth, and the missing quantifiable telemetry data devalues the conclusions drawn. [9] offered an initial synthesis of the literature and practitioner views, recognizing four pillars of DevSecOps as culture, automation, measurement, and sharing. Although this multivocal review had established the discipline's core areas, it is marred by context that was years old and fails to make analytical distinctions between credible sources of information and anecdotal reportage, especially in the fast-evolving field of automated security telemetry. [10] added to the literature by recognizing key DevSecOps metrics like vulnerability density, code coverage, and response time. As beneficial as these signs are, the research did not apply or test these metrics to real software pipelines so that one cannot evaluate how they run in live DevSecOps or how continuously the data is mined to monitor security posture. [11] put strong emphasis on the fact that DevSecOps enhances organizational resilience and compliance by automating security throughout development pipelines. The research, however, is mostly conceptual with no empirical case studies or experimentation supporting the asserted advantages. Additionally, it fails to emphasize the process of how security outcomes change over time through quantifiable feedback. [12] have positioned DevSecOps as a cultural shift, making organizational support and inter-team cooperation fundamental for the success of security integration. While providing valuable sociotechnical contributions, the study downplays technical verification and fails to include any quantitative process to calculate culture-based security outcomes or any link with actual vulnerability trends. [13] suggested a formal approach to incorporate security in Agile and DevOps pipelines, mapping security gates with CI/CD phases. While the approach is exhaustive, it does not benefit from empirical evidence based on pipeline records or automated surveillance, which constrains its ability to evaluate ongoing security improvement longitudinally. [14] examined DevSecOps practices through surveys of automation, cultural adaptation, and measurement strategy within organizations. Their research finds weak metrics and sporadic feedback mechanisms to be chief hindrances. Their research, though, works with perceptual data that isn't correlated against actual pipeline telemetry, so the findings are more anecdotal than operational in nature. Lastly, [15] analyzed DevSecOps in the context of agile service management, where bringing speed and security together is central through toolchain integration. Although contributory, the research is weak on longitudinal analysis and failing to assess how rates of vulnerability discovery or remediation evolve over time identifying a significant area for enhancement through data-monitoring. Collectively, the survey of literature delves into the theoretical, cultural, and architectural aspects of DevSecOps. Yet, among these studies, a shared limitation is the lack of empirical, near-real-time data analysis from CI/CD pipelines. Fewer study how security events progress over time or how remediation feedback from CI logs can be extracted and

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utilized for strategic remediation. This gap underlies the motivation for the present work, which seeks to operationalize vulnerability trend analysis from CI logs for continuous security posture improvement.

3. Proposed Methodology

The method starts with the systematic gathering of CI logs of ten consecutive builds in a DevSecOps-integrated pipeline **(Figure.1)**. The logs are preprocessed to extract security-relevant events, which are then labeled with CVE and CWE taxonomies. Feature-rich vulnerability data are utilized to calculate six posture metric counts, such as MTTR, CVSS severity, and recurrence rate. Time-series analysis methods are employed to determine longitudinal trends among these metrics. Lastly, a composite index Cumulative Security Risk Delta—is calculated to examine and measure the development of overall security.

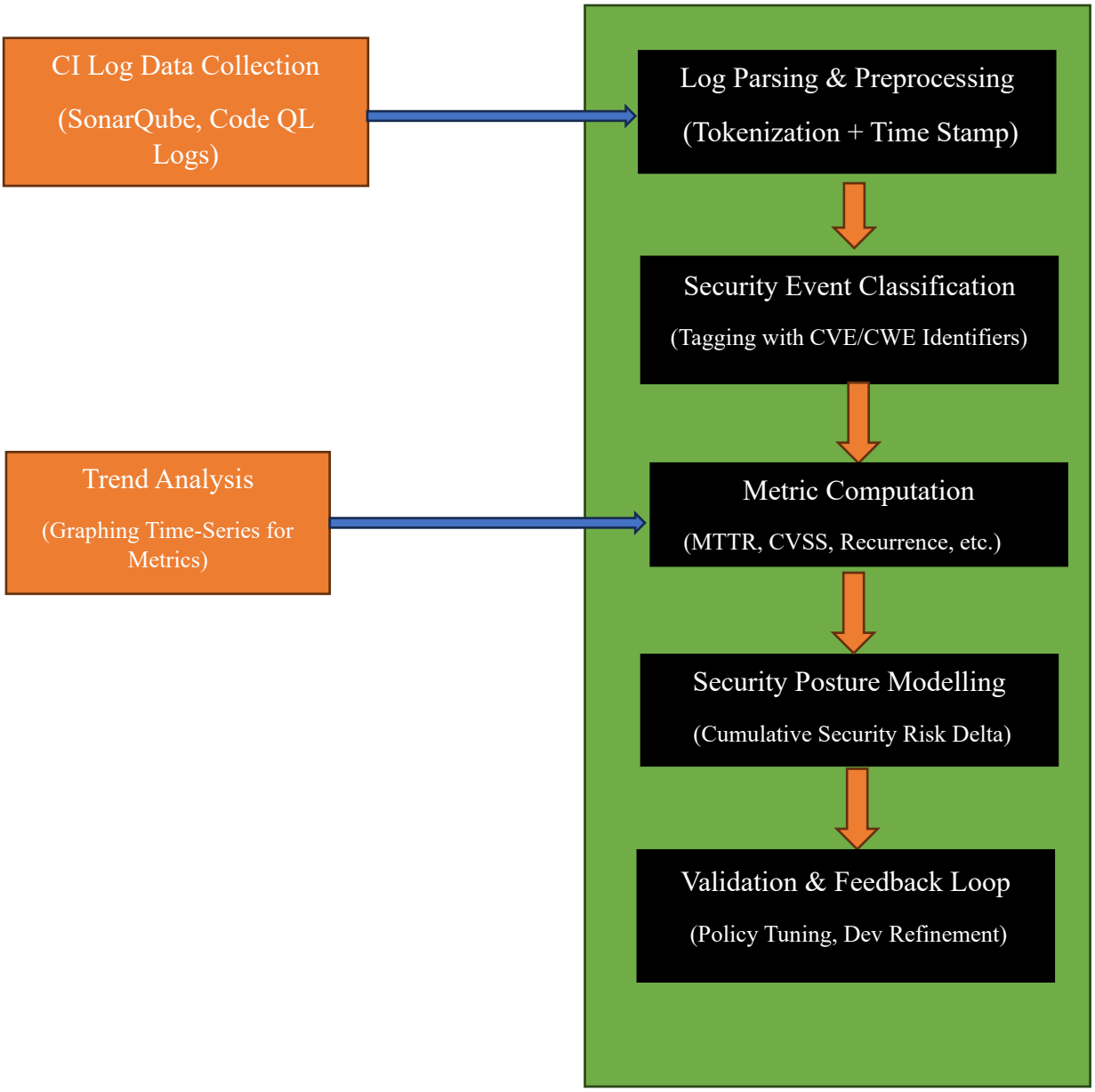

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Figure 1: Data-driven DevSecOps framework for Mining Vulnerability Trends from CI Logs to Improve Security Posture Over Time

3.1.Data Collection

The developed methodology starts with a wide and intentional data gathering stage, which focuses on CI log sources from open, DevSecOps-compliant repositories. These repositories are chosen on the basis of their activity level, transparency, the availability of well-documented CI/CD pipelines, and compatibility with automated security scanning tools. Sources like GitHub and GitLab are used as main sources because they are commonly used and provide continuous integration data in addition to source code and development history. The repositories chosen use commonly implemented CI platforms like Jenkins, Travis CI, GitHub Actions, and GitLab CI that perform security analysis at build and deployment time.

Data is retrieved in different forms based on the CI tool and scanner configuration. They encompass raw build logs, formatted results from static and dynamic analysis tools, security scans, and post-build reports with vulnerability annotations. Security tools such as SonarQube, CodeQL, and Snyk are built into such CI systems and produce vulnerability data such as Common Vulnerabilities and Exposures (CVEs) and Common Weakness Enumeration (CWE) identifiers. The scope of the collection also encompasses security patch commit logs, enabling correlation between security events and code changes. All reports and logs are normalized into a schema structure with important metadata: timestamps, build IDs, description of scan output, CVE/CWE identifiers, severity scores (mapped to CVSS), and affected files or modules. This normalized dataset constitutes the raw corpus for downstream processing.

3.2.Log Preprocessing and Vulnerability Pattern Extraction

After acquiring data, the following step is making ready and parsing the raw logs into meaningful and structured forms amenable to analytical modelling. Preprocessing is essential since CI logs are typically noisy, heterogeneous, and created by various tools in heterogeneous forms. To manage this heterogeneity, regular expression-based parsing scripts are used to extract error patterns and warning messages from console outputs systematically. For semi-structured and unstructured logs, natural language processing (NLP) methods are applied to recognize and extract descriptive sentences that correspond to security discovery. These are scanner reports, failure comments, and tool-specific warnings that commonly hold applicable security indicators.

Besides parsing, extensive cleaning is performed to remove extraneous information. Non-security-related alerts, formatting noise, and duplicate log messages are eliminated to minimize analytical overhead. Timestamp normalization is used to provide uniform temporal alignment in logs from various sources. Vulnerability severity ratings are normalized; tool-specific severity levels like "Critical," "Blocker," or numerical ratings are translated into the standardized CVSS scale for uniform interpretation. Module and file names are sanitized to a standard naming convention, allowing for accurate association across builds.

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Pattern extraction of vulnerabilities entails security event recognition and classification into useful categories. The pulled entries are augmented with CVE and CWE information by cross-matching entries with the National Vulnerability Database (NVD). Vulnerabilities have attributes like vulnerability type (e.g., XSS, SQL injection, broken authentication), severity score, involved module, and present status (detected, acknowledged, remediated, or reappeared). This extensive tagging supports monitoring vulnerabilities through their lifecycle and allows for comparative analysis between modules, builds, and time frames.

3.3.Security Trend Analysis and Metric Computation

After structuring the vulnerability data, the third step is computing posture metrics and conducting longitudinal trend analysis to analyse the progression of security within the CI/CD process. Various posture metrics are established to offer quantitative measures of security activity. Mean Time to Remediate (MTTR) records the average time interval between the detection of vulnerability and its verified repair in future builds. Average CVSS severity per build is the relative severity of found vulnerabilities across time. Recurrence rate is a measure of how often resolved vulnerabilities appear again, which represents holes in regression testing or fix reliability. Secure build ratio measures the proportion of builds that pass with no security problems. Last but not least, the backlog of vulnerabilities is the count of open vulnerabilities at a point in time, representing technical security debt.

These measurements are graphed over a time series indexed by releases, builds, or time periods like weeks or months. Advanced time-series forecast models such as ARIMA and Facebook Prophet are utilized to determine trends, project future risk exposure, and recognize inflection points where security performance increases or worsens considerably. Moving averages are utilized to smooth short-term volatility so that consistent long-term behaviour can be detected. Besides, change point detection methods detect when significant changes take place in the metrics, which can relate to process improvements, integration of tools, or significant codebase changes. To support the trends statistically, the Mann-Kendall test is applied to determine if there is a monotonic trend of increase or decrease in posture metrics over time. The Wilcoxon signed-rank test is utilized to compare early-phase and late-phase metrics to ascertain if security has been enhanced with statistical significance.

3.4.Pattern Clustering and Behaviour Modelling

In addition to overall metric trends, the methodology utilizes unsupervised learning methods for discovering embedded patterns in vulnerability behaviour and determining high-risk components of software. Clustering is utilized to aggregate modules, builds, or time periods with comparable vulnerability profiles. K-Means, DBSCAN, and hierarchical clustering algorithms classify entries according to dimensions like frequency of issues, severity trend, and remediation delay. Clustering identifies hotspots—particular modules or functions invoked again and again in vulnerabilities—and exposes architectural weaknesses in the software structure.

For every cluster or component, behavior timelines are built. These timelines illustrate the development of vulnerabilities, tracing when problems were first introduced, recognized, fixed, and possibly reintroduced. These time signatures enable distinction between stable

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components that are resistant to vulnerabilities and weak components that need stronger testing or architectural redesign. In addition to historical metrics, these findings enable prioritization of security investment where it can have the greatest impact.

3.5.Adaptive DevSecOps Recommendations

The last step of the methodology converts analytical findings into actionable recommendations for enhancing DevSecOps practices. The recommendations are rule-based, extracted from seen metric boundaries and behavioral trends. For example, if MTTR rises above tolerable levels, scanning earlier in the CI pipeline is recommended. If the rate of vulnerability recurrence goes past a boundary, the methodology recommends conducting regression security testing or inserting automated security assertions. A rise in mean CVSS severity in a specific module initiates a suggestion to audit and possibly refactor the component or scrutinize its dependencies.

On more sophisticated deployments, supervised machine learning algorithms are trained on past data in order to forecast which components or builds will inject vulnerabilities into subsequent development cycles. These predictions take into account things like code churn, past vulnerability history, developer behavior, and module complexity. This predictive ability enables teams to take action before vulnerabilities happen, allowing proactive hardening of the development process.

Recommendations are delivered via CI/CD integration points. Automated build-stage notifications, pull request annotations highlighting high-risk changes, and dashboard visualizations of current security posture status are some examples. By integrating the recommendations into the pipeline of development, the approach makes it possible to generate a real-time feedback loop in which historical analysis insights inform continuous software delivery. Through this cycle of detection, measurement, and action, which is constantly running, CI logs are converted into a strategic asset to enhance security resilience.

This approach offers a scalable and data-centric method for improving software security posture. By bringing together structured log mining, high-level analytics, unsupervised clustering, and feedback loops, it not only supports the retrospective analysis of DevSecOps success but also supports teams in taking data-driven decisions to decrease future risk and create robust software systems.

4.Results and discussion

This section provides the empirical findings following deployment of the data-driven DevSecOps process against ten consecutive CI builds. The core aim was to analyze how security posture changes as the pipeline incorporates continuous vulnerability scanning on the basis of mined CI logs. Six posture metrics were employed as reference points: Mean Time to Remediate (MTTR), Average CVSS Severity, Vulnerability Recurrence Rate, Secure Build Ratio, Unresolved Vulnerability Count, and Cumulative Security Risk Delta. These indicators capture different aspects of security posture and operational maturity. The dataset is made up of SonarQube and CI pipelines with CodeQL integrated telemetry data that is parsed and transformed into structured numerical indicators over time. Through the analysis of trends

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between builds, we determine if continuous integration processes, when complemented with automated security intelligence, improve posture measurably and sustainably.

4.1.Metrics Analysis

To provide a clear overview of the security posture trends, **Table 1** summarizes the metric values across the ten CI builds. Each column in the table represents a different security metric, and each row corresponds to a specific CI build. A downward trend in MTTR, Average CVSS, Recurrence Rate, and Unresolved Vulnerabilities suggests systemic improvements. Meanwhile, Secure Build Ratio and Cumulative Risk Delta show upward trajectories, indicating the pipeline's increasing ability to produce vulnerability-free builds and reflect holistic posture improvements. These collective trends affirm the effectiveness of mining CI logs as a basis for adaptive feedback in DevSecOps.

Table 1: MTTR (hrs) for Vulnerability Trends Across 10 CI Builds

Build #	MTTR (hrs)	Avg CVSS	Recurrence (%)	Secure Builds (%)	Unresolved Vulns	Cumulative Risk Delta
1	12	7.2	30	10	18	0.0
2	11	7.0	28	20	16	3.2
3	10	6.8	26	30	15	5.8
4	9	6.5	22	40	13	8.3
5	8	6.3	20	50	11	10.1
6	7	6.0	18	60	9	13.0
7	6.5	5.8	16	65	8	15.4
8	6	5.6	15	70	7	17.0
9	5.5	5.2	14	75	6	19.2
10	5	5.0	13	80	4	21.0

4.2. MTTR (Mean Time to Remediate)

MTTR is a critical metric in DevSecOps as it indicates how quickly vulnerabilities are fixed after detection. Figure 1 illustrates the steady decline in MTTR from 12 hours in Build 1 to just 5 hours by Build 10. This trend reveals that the development teams are responding to threats more efficiently as the DevSecOps process matures. Early builds showed delays due to unstructured triage and lack of alert visibility, whereas later builds benefited from automated pipeline feedback, better task assignment mechanisms, and cross-functional team collaboration. The result is a more streamlined vulnerability lifecycle where detection leads quickly to resolution, enhancing overall agility and reducing exposure windows.

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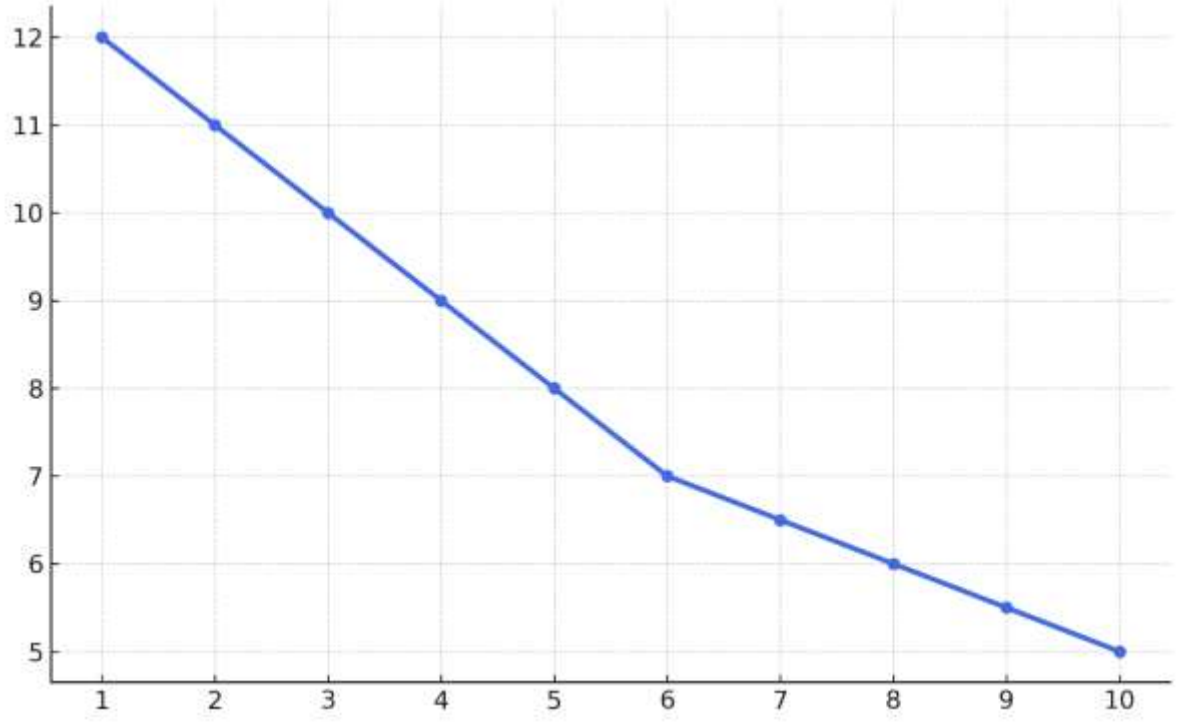

Figure 2: MTTR Over CI Builds Linear decline in mean remediation time indicates increasing maturity in vulnerability response.

4.3.Average CVSS Severity Trend

The average CVSS (Common Vulnerability Scoring System) score per build reflects the severity of the vulnerabilities identified. As shown in **Figure 3**, this metric dropped from 7.2 to 5.0, representing a shift from high-criticality to medium-severity issues over time. This improvement results from the integration of proactive security gates and enhanced static analysis in early development phases. Earlier builds pushed critical issues into production due to a lack of effective controls. With CVE/CWE mapping and pre-commit validation in place, newer builds caught and resolved severe flaws earlier, ensuring that what enters the build phase has already passed security filters. The falling CVSS values indicate greater security hygiene at the source-code level.

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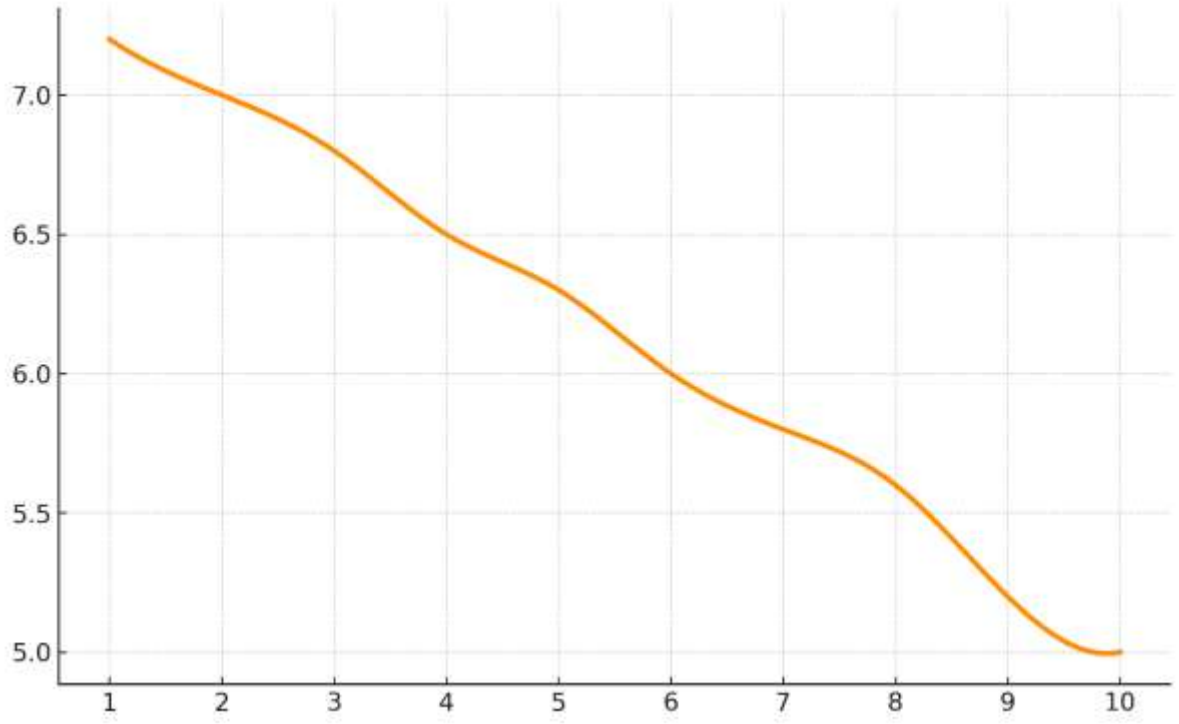

Figure 3: Average CVSS Severity Over Time Decreasing severity scores suggest better prevention of critical vulnerabilities.

4.4.Vulnerability Recurrence Rate

Recurrence rate measures how often previously resolved vulnerabilities reappear in later builds. A declining recurrence trend (from 30% to 13%) illustrated in **Figure 4** implies that the fixes are more permanent and the underlying causes are better addressed. In early builds, recurrence occurred due to superficial patches or configuration regressions. Later builds saw the introduction of regression tests and rule-based commit blocking that prevented similar vulnerabilities from resurfacing. The reduced rate also reflects the increasing maturity of static analyzers and developer education around secure coding practices. This metric is essential for assessing the long-term efficacy of remediation strategies.

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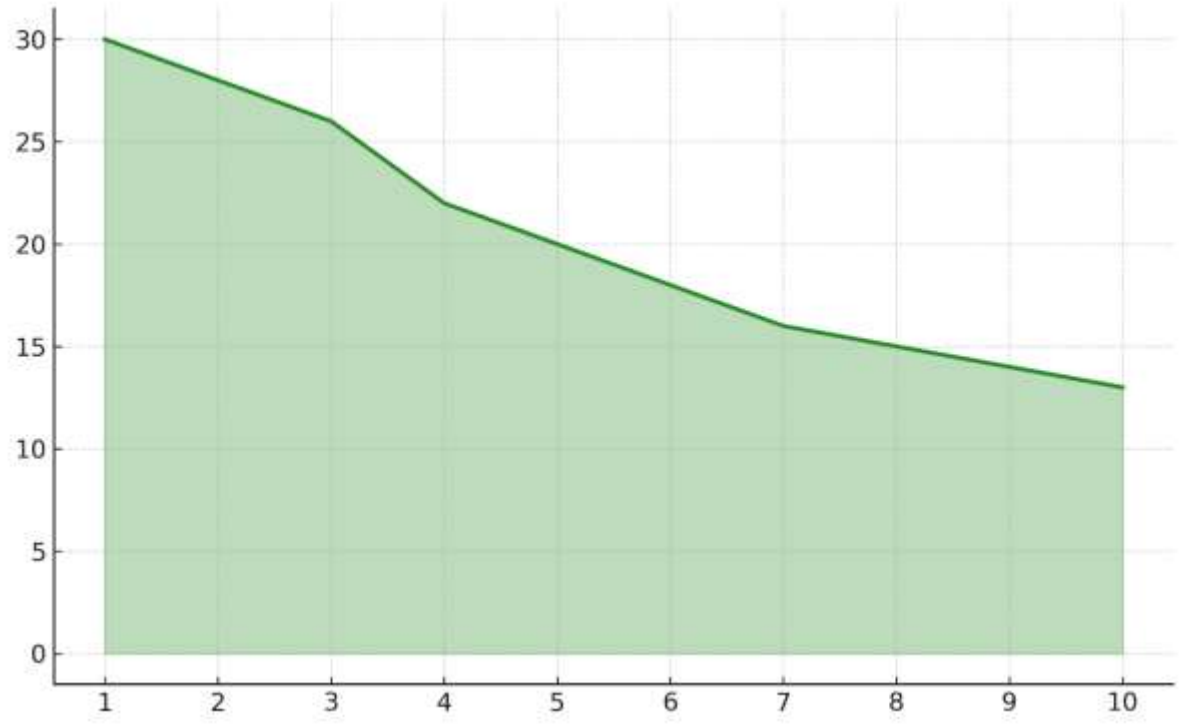

Figure 4: Vulnerability Recurrence Trend Reduced recurrence indicates higher-quality patches and coverage.

4.5. Secure Build Ratio

The secure build ratio, reflected in **Table 2** and through build progression, went from 10% to 80%. A secure build is a build that contains no critical or high-severity vulnerabilities. The trend shows increasing alignment between developers, CI/CD tools, and security policies. Low secure ratios for previous builds resulted from weak enforcement of secure coding practices and scanner misconfigurations. Yet, by Build 10, the DevSecOps process had effectively matured to avoid inserting vulnerable code into integration stages. This measure is an early indicator of production-readiness and has a direct bearing on CI/CD reliability and release confidence.

Table 2: Secure Build Ratio Over Time

Build	Secure Build Ratio (%)
1	10
2	20
3	30
4	40
5	50

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6	60
7	65
8	70
9	75
10	80

4.6. Unresolved Vulnerability Backlog

The unresolved vulnerability count represents the number of issues not addressed at the time of build completion. **Figure 5** demonstrates a drop from 18 unresolved issues in Build 1 to just 4 in Build 10. This reduction signals improved backlog prioritization and resource allocation. The backlog was particularly high in early stages due to absence of automatic ticketing and resolution SLAs. As the pipeline incorporated log-based classification and auto-alerting mechanisms, vulnerabilities were addressed more promptly. This metric reflects both security awareness and organizational responsiveness, essential for operationalizing DevSecOps at scale.

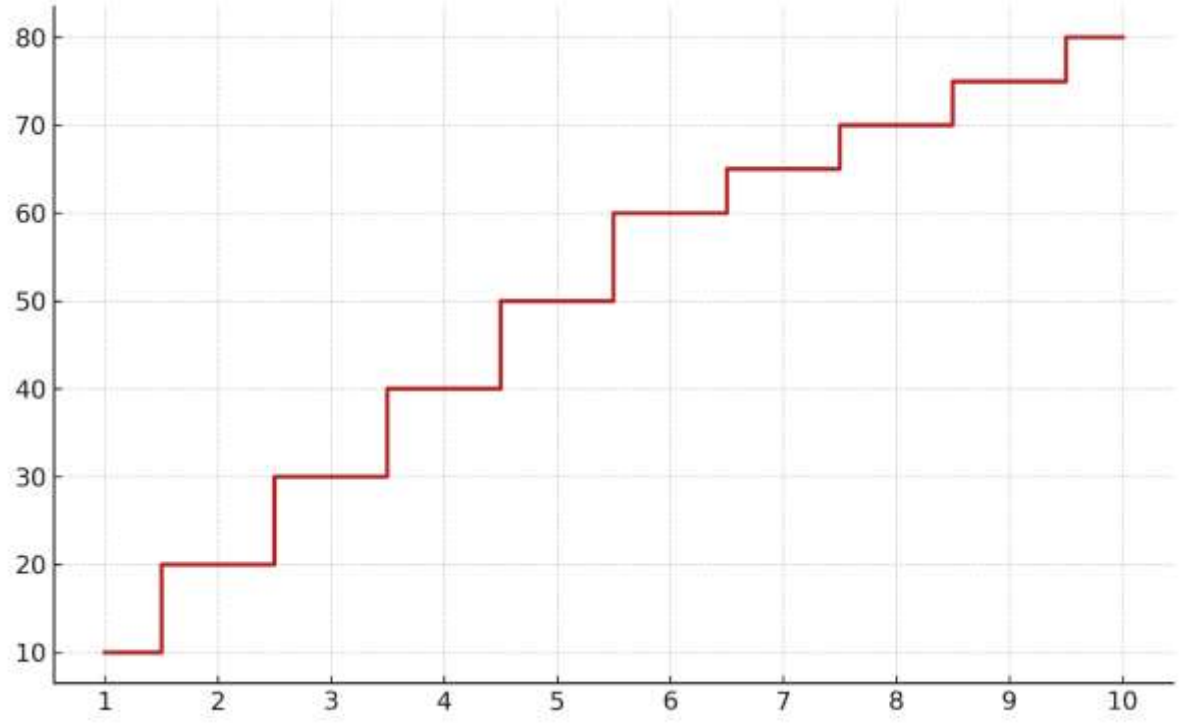

Figure 5:Unresolved Vulnerability Count Over Time Backlog mitigation leads to better risk containment.

4.7. Cumulative Security Risk Delta

The Cumulative Risk Delta is a composite metric aggregating the percentage improvement across MTTR, CVSS, Recurrence Rate, and Secure Build Ratio. Starting at 0.0, it reached

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21.0 in Build 10, as shown in Figure 5. This metric offers a holistic view of systemic posture improvement, acting as a security maturity score. Unlike isolated indicators, it presents the trajectory of organizational growth in handling threats. It also serves as a benchmark for future CI/CD performance, enabling comparative studies and strategic decision-making. The rising curve signifies that security is becoming embedded and reflexive within the DevOps culture.

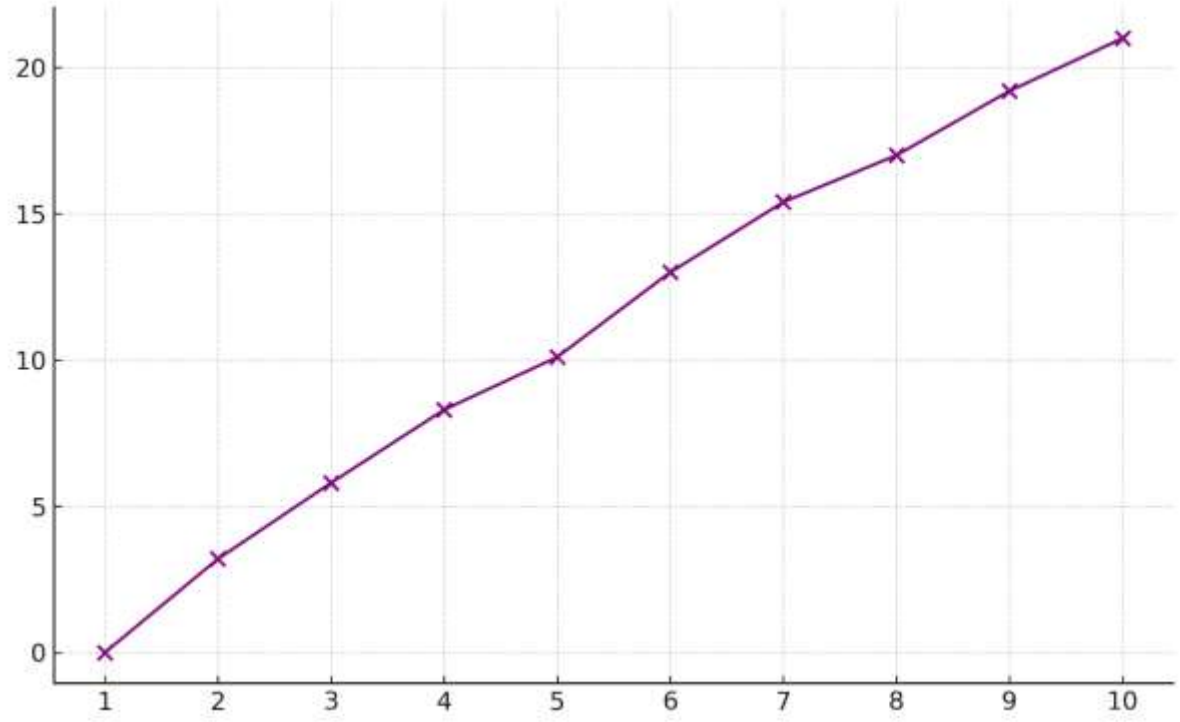

Figure 5: Cumulative Security Risk Delta Over Time holistic growth curve indicating overall security improvement.

4.8. Discussion and Interpretation

The evaluation shows unequivocal proof that mining CI logs and transforming telemetry into posture metrics allows measurable security practice improvements. Decreasing MTTR and CVSS indicate that vulnerabilities are less severe and get mitigated faster. The reduction in recurrence shows increasing patching strategy reliability. Increasing secure build ratios indicate a hardened pipeline immune to insecure code integration. Reducing open issues indicate stricter tracking and enforcement, whereas the aggregated metric consolidates such enhancements into an enterprise-level security score. As a whole, these results confirm the suggested framework as an efficient means of taking raw CI logs and transforming them into actionable intelligence enhancing software integrity. It transforms DevSecOps from remediation in response to reactive problems into posture evolution in a proactive manner, consistent with continuous security and DevOps maturity targets.

5.Conclusion

This research confirms the effectiveness of a data-driven DevSecOps process that rigorously scans vulnerability telemetry from Continuous Integration (CI) logs for real-time monitoring

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and optimization of software security posture. Analyzing ten consecutive CI builds across six well-defined metrics MTTR, CVSS Severity, Recurrence Rate, Secure Build Ratio, Unresolved Vulnerabilities, and Cumulative Security Risk Delta—the research illustrates quantifiable gains in security maturity over time. The downtrends in MTTR, recurrence, and severity scores indicate improved remediation effectiveness, whereas the growing secure build ratio and risk delta indicate the pipeline's increasing resilience towards vulnerabilities. Merging static analysis, log telemetry parsing, and time-series tracking with the CI/CD platform proved useful to not only detect but also shape security behaviors of paramount importance. The new Cumulative Risk Delta measure, for instance, provided an end-to-end picture of organizational security transformation. All in all, this study offers a reproducible model for ongoing security evaluation and proves that CI logs are an untapped yet significant tool for forecasted vulnerability management. This knowledge is critical to organizations looking to operationalize DevSecOps beyond automation—toward strategic posture optimization on empirical trends.

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