Automated Security Testing in DevSecOps Pipelines

Research Report

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ABSTRACT

This research report focuses on the integration of automated security testing in DevSecOps pipelines to ensure continuous security throughout the software development lifecycle. Traditional manual security testing methods face challenges in DevOps environments due to the fast-paced nature of software development, necessitating the adoption of automated approaches. The report conducts a comprehensive literature review to examine existing studies and tools for automated security testing in DevSecOps. Furthermore, explores various techniques such as static analysis, dynamic analysis, software composition analysis, and penetration testing, assessing their benefits and limitations. The report continues with an evaluation and selection of suitable tools and frameworks. It proposes an architecture for integrating automated security testing and presents the implementation of a sample DevSecOps pipeline using selected security testing tools. The results demonstrate the effectiveness of automated security testing in identifying vulnerabilities and security weaknesses compared to manual methods. The report discusses the advantages of integrating automated security testing in DevSecOps pipelines, addressing practical challenges and offering potential solutions. It provides best practices and guidelines for tool selection, defining security test cases, and integrating security testing into CI/CD processes. The report concludes by summarizing the findings, emphasizing the significance of continuous security testing in DevSecOps, and outlining future research directions. The outcomes of this research contribute to enhancing the understanding and adoption of automated security testing practices in DevSecOps, and in result improving software security in agile development environments.

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# INTRODUCTION

In today's digital realm, a secure software application is an absolute requirement. With the ever-increasing cyber threats, organizations now fully acknowledge the significance of robust security measures at every stage of software development. This has given rise to a methodology called DevSecOps, which integrates security practices seamlessly into development and operations processes. DevSecOps signifies a change in software development, highlighting the importance of considering security from the beginning rather than treating it as an afterthought. It acknowledges that traditional security approaches, which relied on manual testing by dedicated security teams, are insufficient in the fast-paced DevOps environment. This means that in the DevSecOps process every developer working on the software is responsible for the security of the software.

As organizations strive to deliver software faster and more frequently, maintaining adequate security measures has become increasingly complex. With the rapid development cycles and continuous deployment practices of DevOps, traditional manual security testing struggles to keep up. Manual testing is time-consuming, prone to errors, and often lacks comprehensive coverage. Consequently, critical vulnerabilities may go undetected until it's too late, leaving applications and users exposed to potential breaches and data leaks. To tackle these challenges, automated security testing has emerged as a crucial element of DevSecOps. By utilizing automation tools and techniques, organizations can improve the speed, accuracy, and coverage of security testing within their development pipelines. To ensure the effectiveness of automated security testing, however, it is vital to identify the key vulnerabilities and threats that require specific attention.

This research investigates the primary security weaknesses and risks that automated security testing should concentrate on in DevSecOps pipelines. The goal is to explore effective methods of integrating automated security testing into DevSecOps pipelines to guarantee consistent security across the software development lifecycle.

The report starts by stating the research objective in the form of a main question and related sub-questions. These questions define the research scope, covering various topics and processes to ensure the research's quality, comprehensiveness, and direction.

The main part of the report will present the findings from the literature review and the results obtained from the tasks and tests performed during the research. It will also detail the setup of the testing environment utilized. Additionally, a series of steps and explanations will be provided to describe the process that led to the findings, including the various technologies involved.

In its conclusion the report will remark on all the results of the research as well as the findings and will explain how that answers the goal/main research question.

# METHODOLOGY

**Main research question:**How can automated security testing be effectively integrated into DevSecOps pipelines to ensure continuous security throughout the software development lifecycle?  
  
**Sub-questions with methodology:**

* **What are the key security operations that automated security testing can focus on within** **DevSecOps pipelines?**
  + Library (Best Good and Bad practices)  
    Figuring out common practices when it comes to automated testing.
  + Field (Task analysis)  
    Gain a proper understanding of the tasks that automated testing seeks to complete.
* **What are the measurable benefits of integrating automated security testing into DevSecOps pipelines, such as improved vulnerability detection and reduced time to remediate?**
  + Library(Literature study)  
    Find general information on the benefits of automated security testing.
  + Library(available product analysis)  
    Find out what others who implemented automated testing found to be beneficial about it.
  + Lab(Security test)  
    Extrapolate from the testing that has been done for this research to the potential benefits
* **What criteria should be considered when selecting automated security testing tools for integration into DevSecOps pipelines?**
  + Showroom(Product review)  
    Evaluate the technology in order to determine if it’s valuable for the use case that it is looked up for.
  + Workshop(Multi-criteria decision making)  
    Which criteria is more important to consider for each type of automated testing and which tool is the best overall.
* **How to setup and integrate the chosen tools in the DevOps process for consistent and continuous security checks?**
  + Library (Available product analysis)  
    Find out what levels of automation do the tools offer and how they function.
  + Field (Document analysis)  
    Read different tools’ documentation to better understand their function.
  + Workshop (Prototyping)  
    Use the available technologies in order to better evaluate them

# RESULTS AND CONCLUSIONS

*Showcasing the findings of the literature study and the results derived from the tasks and tests performed throughout the research.*

## What are the key security operationsthat automated security testing can focus on within DevSecOps pipelines?

**Code Quality (SAST)**

Automation is a fundamental aspect of the DevOps process, and when security is integrated throughout, it becomes the DevSecOps process. In this context, the DevSecOps process can be viewed as augmenting each level of the DevOps process with security features. The initial stage of the DevOps process involves pushing software code to a git repository. Consequently, it is logical to consider static application security testing (SAST) as the first type of security automation.

Static application security testing involves scanning the application code to identify potential issues, including security vulnerabilities. Those issues include vulnerability detection, early bug identification and enforcing secure coding practices among others. The process of static code analysis can begin even in the IDE by installing a real-time developer SAST tool such as Sonar Lint or Code Sight. SAST does not even require a complete application in order to start working. After installing the required tool a developer can just continue the development process as usual but now they will be notified in real time about the mistakes they are making in their code.

Static application security testing is also available as a complete application scanner tool that is also easy to integrate into a CI/CD pipeline. After a simple installation the tools can be configured to perform a scan of the application’s code on each push to the git repository. Furthermore some tools can be configured to require a manual check by a developer before letting the pipeline continue. This adds extra layer of security but might also slow down the process as it eliminates some of the advantages of the automation of the process. (9)

**During the Building process (Unit Tests)**

Unit testing is the process of testing down to the different structures like functions, methods or classes of the code. They are predefined set of tests that serve as a verification whether each unit of code that is being tested works as intended. There are different methodologies that allow unit testing to be integrated seamlessly into the DevSecOps process such as test driven design or TDD. TDD is the practice of writing the automated test before writing the code.

1. **Test**: The TDD process starts by writing test cases that specify the expected behavior of the code. These tests are created using a suitable testing framework for the specific programming language or platform. Initially, the tests are designed to because since the corresponding code has not been implemented yet.
2. **Code**: Once the test cases are in place, the developer focuses on writing the minimum amount of code necessary to make the tests pass. The code is implemented to fulfill the requirements specified in the unit tests. It is crucial to only focus on making the tests pass and avoid adding any extra code beyond what is required.
3. **Refactor and Repeat**: After successfully passing the tests, the code can be refactored. Refactoring involves restructuring the code without changing its external behavior. This step is important for improving the code's design, readability, and maintainability. The goal is to ensure that the code remains clean, efficient, and well-structured. Once the refactoring is done, the cycle repeats by creating additional test cases that define the next desired functionality.

Unit tests can easily be ran through the pipeline as part of the DevSecOps automation. Usually this is the step before building the application in the pipeline. (8)

**Software Composition Analysis (SCA)**

Open source libraries are a part of most applications today, however, using open source code can easily introduce a lot of vulnerabilities to the software. This is why SCA testing is an important part of the DevSecOps process. SCA is the process of automatically analyzing and managing open source and third-party software that are used in the application. This is performed in order to check if an outdated version of the third party software is used or maybe a version that has a known vulnerability in it. The npm package provides some build in SCA functionality which analyzes the application’s dependencies and it comes preinstalled.

The SCA tool first scans the software composition in question and defined the third party software. Consecutively, it provides information about each module including the license under which the software is distributed, whether the software requires any conditions to be met before using it and whether the license is compliant with the licenses that are allowed in the organization or if any such restrictions are present in the first place. Finally the SCA software ties to identify any vulnerabilities inside the third party software that are either the result of an outdated version being used (in which case the SCA software offers to update it to it’s latest version) or the software has a known vulnerability in which case the SCA might offer a solution to the problem. (10)

**Dynamic application security testing (DAST)**

Dynamic Application Security Testing (DAST) is a broad term that encompasses various techniques and tools used to assess the security of applications at different stages of their development. DAST offers flexibility, allowing for the application of diverse approaches and methodologies to achieve a comprehensive security assessment. One facet of DAST involves utilizing an API fuzzing tool. This tool focuses on thoroughly testing all endpoints of an API, aiming to identify vulnerabilities or uncover potential issues that could lead to API failures. By generating a high volume of malformed or unexpected inputs, the fuzzer tests the API's robustness and evaluates its ability to handle unforeseen data correctly. The objective is to expose vulnerabilities or situations where the API may break, enabling developers to implement necessary measures to fortify its security and enhance its ability to withstand potential attacks.

Additionally, DAST can refer to the usage of automatic application scanners, which are integrated into the testing process following the deployment of the application in a dedicated test environment. These scanners simulate attacks and interactions with the application's front-end interface, specifically targeting security flaws such as injection attacks, cross-site scripting, and other vulnerabilities. By actively testing the application's behavior, these scanners provide valuable insights into potential weaknesses that could be exploited by malicious actors. As a result, DAST is categorized as a type of penetration testing - its purpose is to discover vulnerabilities and potential entry points that attackers could exploit in an application. By analyzing the application's behavior and how it responds to different attack scenarios, security experts can identify areas of concern and offer suggestions for fixing them.

DAST tools offer valuable automated testing capabilities, however, they may not uncover all vulnerabilities, particularly those that require manual analysis or a deep understanding of the application's underlying logic. Therefore, it is often best to combine DAST with other testing approaches, such as Static Application Security Testing (SAST) or manual security assessments. This combination ensures a comprehensive evaluation of the application's security, leaving fewer chances for vulnerabilities to go undetected. (4)

**Container scanning**

Containers are the main structure when it comes to building today’s application architectures. Whether it would be a single container or a multiple container deployment all applications can benefit from container security. Containers have multiple layers that can each introduce vulnerabilities to the system. This is why container scanning is important.

Container scanning is the automated process of analyzing the content of container images to identify potential vulnerabilities or security issues. Containers act like complete runtime environments in their way of storing, executing, and packaging the application and it’s dependencies. Therefore, they can have similar vulnerabilities and furthermore, any library that the container includes adds another potential for vulnerabilities. By introducing container scanning during the development process the developer minimizes the risk of deploying vulnerable containers of their application into production. This is most optimally performed in the CI/CD pipeline as part of the dev ops process automation, before the deployment phase as that way it would add a final check of the containers before they get exposed to the outside world. (7)

## What are the measurable benefits of integrating automated security testing into DevSecOps pipelines, such as improved vulnerability detection and reduced time to remediate?

The purpose of CI/CD pipelines is to automate the development process by performing repeatable tasks that would require way too much time to setup and perform manually. The same can be said about automated security testing in the CI/CD pipeline. There are numerous benefits to such automation that are worth the time and effort that it takes to setup. These benefits range from faster and efficient security testing process and improved security to better information gathering, earlier vulnerability awareness, continuous level of security assurance and quicker vulnerability patching.

**Faster and efficient security testing**

Manual security testing is difficult and time consuming. By integrating automated security testing tools into the CI/CD pipeline, security tests can be executed quickly and efficiently. Static code analysis tools can scan the codebase for potential security vulnerabilities, such as insecure coding practices or known vulnerabilities in third-party libraries. Dynamic application testing tools can simulate attacks and identify security weaknesses in the running application. Container security tools can analyze container images for vulnerabilities and misconfigurations. This largely eliminates the need for manual testing and therefore improves the speed at which security is tested inside the CI/CD pipeline (11)

**Early feedback and reduced time to remediate**

Automated security testing speeds up the detection and fixing of vulnerabilities. By catching security issues early in development, teams can address them quickly, saving time and preventing complications. This results in shorter time-to-market for software releases. Integrating security testing into the DevSecOps pipeline provides immediate feedback on security risks. Developers receive instant notifications about security issues, allowing them to promptly resolve problems. This early feedback loop enhances teams' understanding of the security impact of their code changes, enabling proactive risk assessment and mitigation. In comparison, manual testing also has it’s benefits such as more in-depth testing and smarter penetration tests however it needs to be performed by security experts and requires much more time. (12)

**Enhanced compliance adherence**

For companies that are especially focused on security such as banks, healthcare companies and government sectors CI/CD integration of security into the development process allows faster and more thorough adherence to security regulations. A DevSecOps pipeline that integrates security testing promotes collaboration between development, security, and operations teams. This collaboration helps foster a security-aware culture inside the organization and ensures that security concerns are addressed as a focused collective rather than an afterthought. By introducing the process of security earlier in the development process these companies can more easily ensure that their software is compliant with all regulations and provides the needed security levels that they require. (13)

## What criteria should be considered when selecting automated security testing tools for integration into DevSecOps pipelines?

With the growing importance of cybersecurity and the rising popularity and adoption of the DevSecOps process, there has been an increase in the availability of testing tools on the market. This necessitates the definition of criteria which will be helpful when choosing the correct tool for the job. There are a lot of criteria that can be looked at however the most important for the sake of automation the tools should be easy to use, cheap and ci/cd integratable.

**SAST**

There is a large number of available static application security testing tools. So in order to evaluate them a set of criteria needs to be taken into account. The first criteria to look at when taking into account static code analysis is the capabilities of the tool – is the tool able to work with the selected language or framework that is being used to create the application in the first place and if so how capable is it in doing so.  
Next is the platform agnosticism or how well does it integrate into different platforms whether that is the type of ci/cd pipeline that is being used or the ide.

Finally the price of the tool is also important as it is very easy to ramp up the price with automation tools such as those. Some tools offer free versions and only charge on the integration. Other companies charge on lines of code scanned. With so many things that can be monetized it is important to know in order to determine the worth to cost ratio.

The tool that will be shown in this example is one that covers all these requirements – SonarQube. It is one of if not the most popular SAST tool on the market. It is an open source tool that offers a free version. The only charges can be accrued are related to the hosting of the tool so if that is covered then the free version is good enough to use. For this research I’m going to be scanning an application that is written in TypeScript using NodeJS and the Express framework. Typescript/JavaScript is one of the 15 languages that SonarQube supports, therefore it is covered. SonarQube also has a very easy time integrating into a CI/CD pipeline as it already has some pre-prepared configuration options and menus inside most git repositories such as Azure DevOps and GitHub. (14)

**Unit Testing**

When creating unit tests for JavaScript and TypeScript there are two major tools that are the most used - Mocha and Jest.

Mocha is an open source, older testing tool and therefore it has a large user base and is well supported. It is more complicated than Jest as it has more options. Therefore, it can be more difficult to learn with the upside of the fact that an experienced user can achieve a lot with it. (15)

Jest is a tool that was developed by the team of Facebook. It is a faster version of Mocha that offers different advantages such as automatic test execution during the development process in order to see if the changes are still congruent with the tests. This is ideal for test-driven-development. In the past it did not support async testing which was a big downside however in the recent years some workarounds have been introduced that help in that regard.

The tool that is going to be shown in this example is Jest as it is an easier tool to learn and offers good automation. Most of the things that disparage it from Mocha have a workaround or have been resolved already. (16)

**Software Composition Analysis (SCA) and Container scanning**

The key features to looks for in a SCA tool are the ability to scan open sourced software such as modules, frameworks and packages that are a part of the software application that is being scanned. It is important that such a tool can detect known vulnerabilities in open-source software modules and do it thoroughly and fast.

Furthermore an SCA tool might have capabilities to scan a docker container which is a huge advantage.  
  
For this section the tool that is going to be shown in the practice example is Snyk. Snyk is a security company that offers multiple tools for full software coverage. They have a dedicated SCA tool and a dedicated Container scanner tool which should cover all bases. Furthermore, their software is free to use at a 200 tests a month rate which is more than enough for this use case. (19)

**DAST**

In terms of dynamic application security testing the most important aspects to look at are ease-of-use, scan effectiveness and price.

In this report the tool that is going to be shown is OSWASP ZAP. It was chosen on the basis of it being completely free to use and integrate into a ci/cd pipeline. (17) Other tools such as Burp Suite are more developed and easier to setup however they offer the same scanning potential and require payment for the enterprise version of the software which means that they can’t be integrated into a CI/CD pipeline for free. (18)

## What are the existing automated security testing tools and frameworks available for integration into DevSecOps pipelines?

**Unit tests with Jest**

Setting up unit tests in a Typescript application can be done very easily with Jest. First an install is required as Jest is a third party software.

|  |  |
| --- | --- |
| A screen shot of a computer program  Description automatically generated with medium confidence  Figure - Package.json | The package.json of the project containing information about the jest setup. Because the application uses Typescript we need to install the types declaration as well with **@types/jest.** |

|  |  |
| --- | --- |
| Figure - jest.config.js | The next step is to configure the **jest.config.js** configuration file so that it knows that it should use the **ts-jest** preset in order to run typescript tests as well as define the tests folder from where they can be started automatically using the “jest” command. |

|  |  |
| --- | --- |
| A screen shot of a computer program  Description automatically generated with low confidence  Figure - Unit Test example | An example of one of the unit tests in the application. The test begins with an import of the service that is being tested after which it is mocked along with all of its dependencies.  Then all the functions that are going to be tested are imported as well.  A description of the test file is defined and after that so is a description of the first unit test in this document.  The “createSession” unit test begins with a definition of a user and a userAgent. These are random test values that are needed for the creation of a session.  The function is called with the hardcoded values. The test checks whether the function was called correctly and whether the result is equal to the hardcoded value. |

A screen shot of a computer

Description automatically generated with low confidence

Figure - Test trigger script with --coverage option

The test trigger script can be called with the command “**npm run test**”. The –coverage option describes an automatic generation of a “coverage” directory that is automatically created inside the base directory for the project. The purpose of this directory is to communicate to SonarQube of the percentage of unit test coverage for this project.

A screenshot of a computer program

Description automatically generated with medium confidence

Figure - Unit test report and coverage report

After the test suites are ran a report is generate with the names of the tests and whether they passed or not, along with the coverage report.

SonarQube (SAST)

A screenshot of a computer

Description automatically generated with medium confidence

Figure - SonarQube deployed on a VM on Azure Cloud

The SonarQube setup has been successfully deployed and configured on an Azure virtual machine (VM). Due to limitations in the subscription, the automatic SonarQube setup from the Azure Marketplace could not be utilized. This is why, a manual deployment had to be carried out on an Ubuntu VM. This approach takes a lot longer to setup but is just as viable.

A screenshot of a computer

Description automatically generated

Figure - SonarQube is accessible from it's IP on port 9000

A screenshot of a computer

Description automatically generated with medium confidence

Figure - SonarQube Dashboard after login.

I will be using GitHub actions to connect and configure automatic SonarQube scans.

|  |  |
| --- | --- |
| Figure - SonarQube with unit tests coverage metrics | The .yaml file that is going to trigger unit testing and SonarQube scan.  The ENV variables come from GitHub repository secrets where they have been setup beforehand.  The job runs on a latest version of Ubuntu. The first step is to clone the repository tot his environment.  After that it’s time to install the dependencies with npm install inside the microservices’ directories where the unit tests reside so that the tests can be ran.  Consequently, the tests are ran from all directories where tests reside.  Finally SonarQube is ran. It uses a preconfigured token and a URL in order to connect to the deployed version of SonarQube. |

A screenshot of a computer program

Description automatically generated with low confidence

Figure - sonar-project.properties Sonar Scan configuration file

SonarQube requires a configuration file in the project base folder that contains explanations that help SonarQube to navigate the project, include, and exclude different files and directories from being scanned.

Finally after the static code analysis is finished

A screenshot of a computer

Description automatically generated with medium confidence

Figure - Completed SonarQube scan with 0 bugs and 19 smells inside 3000 lines code (The fail is because of only 18% unit test coverage)

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