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Performance Analysis of CI/CD Pipelines for Terraform-based Docker Deployments

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Performance Analysis of CI/CD Pipelines for Terraform-based Docker Deployments

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Abstract

Cloud-native software is heavily dependent on Continuous Integration and Continuous Delivery (CI/CD) pipelines to facilitate the process of automated, scalable and efficient deployment of applications. Nevertheless, the organizations lack empirical advice regarding the CI/CD platform is most effective with the Infrastructure-as-Code and containerised workloads, especially when implemented using Terraform in cloud providers. This gap is addressed in this report by comparing three popular CI/CD tools – GitHub Actions, Jenkins and AWS CodePipeline, performing the running of Dockerized Django applications Dockerized using Terraform on AWS. In order to maintain a consistent evaluation, a bespoke Metrics API and real-time Dashboard was developed to assemble five new cloud-specific performance measurements, namely: Layer Cache Efficiency (LCE), Pipeline Recovery Time (PRT), Secrets Management Overhead (SMO), Dynamic Environment Time (DEPT), and Container Layer Build Consistency (CLBC). The results demonstrate that GitHub Actions is the most ideal cloud-native and has excellent caching performance, stable image building, and expeditious recovery performance. Jenkins had poor caching and environmental variability with self-hosted runners as well as being highly configurable. The AWS CodePipeline was highly reproducible, lacks have high provisioning overhead as it is a multi-layered, orchestrated deployment. These results validate the existence of large differences in cloud- native CI/CD behaviors even with the same workload, and that the conventional metrics cannot be used to reflect more profound operational features. The research offers a reproducible benchmarking model and offers viable implications to DevOps teams choosing CI/CD applications to deploy cloud resources using Terraform. This finding will provide a base of future studies that will include multi-cloud comparisons, microservices-scale testing, and incorporating DevSecOps performance metrics.

1 Introduction

1.1 Background

Cloud computing has transformed modern software development through providing the ability to scale, automate and elasticize application deployments. The pressure to ensure that delivery processes are reliable, standardized and automated has been increased with the rising preference towards cloud-native systems. The CI/CD pipelines are integral part of transformation by providing the automation of the integration, testing and deployment of the application. Infrastructure as Code (IaC) tools like Terraform and containerization technology like Docker can be listed among the key elements of the infrastructure reproducibility and standard application packages, which is why these tools are classified as the essential elements of modern DevOps practices alongside the concept of CI/CD. The most widely used tools in the CI/CD environment are GitHub Actions, Jenkins and AWS CodePipeline and each has different architecture, mode of execution, scalability, and cloud connection. Even though current literature discusses the concept of CI/CD or the analysis of separate tools, there is not much empirical data that compares these platforms under the same conditions of cloud-native deployments with a uniform workflow based on a consistent Terraform and Docker workflow. The majority of comparative studies use generic performance like build time and success percentage that do not reflect more operational behavioral patterns that shape cloud-based delivery. Consequently, organizations that need to optimize their pipelines lack a dependable guideline on the most suitable CI/CD platform to use on AWS environments.

Under these conditions, it is highly desirable to have a systematic and objective benchmarking strategy that will access CI/CD tools based on cloud native performance features and not on conventional metrics alone. Reproducible builds, effective caching, fast recovery mechanism and consistent deployment propagation are becoming increasingly important in modern software teams, but these operational characteristics are not well studied in academic literature. Since organisations keep growing their DevOps practices, it is essential to comprehend the behaviour of CI/CD tools will respond to the same infrastructure conditions, to reduce the risk of deployment, enhance the productivity of the developers and reduce operational overhead. A more metrics-based comparison also offers more concrete guidance on the choice of the appropriate tool depending on technical needs as opposed to anecdotal or vendor-based arguments.

1.2 Importance and Motivation

Effective CI/CD pipelines have a direct influence on the speed of software delivery, reliability and its efficiency. Even slight variations in pipelines performance (reduced caching, increased failure rate, or increased environment provisioning) in a cloud environment will compound to large amounts of development time and workloads. The usage of GitHub Actions, Jenkins and AWS CodePipeline are widely used, there is no controlled, data driven comparisons that show how the three platforms perform when they are used to run the same deployment workflow on AWS with IaC and containerization. Most of the

existing work focuses on general CI/CD metrics such as build time, test time and failure rate, which lack in describing for cloud-specific behaviors like caching effectiveness, pipeline recovery or deployment consistency during dynamic environments. This leaves the engineers and architects with a gap that requires a selection of CI/CD tool that fits their infrastructure, performance expectations, and operational constraints. This research is driven by the necessity of offering a rigorous, cloud- based benchmarking framework to access CI/CD platforms by relying on both conventional metrics and proposed cloud-native metrics, which provide a more detailed understanding of the behavior of a pipeline.

1.3 Research Question

How effectively can the performance of modern-day CI/CD pipelines in infrastructure-as-code workflows be measured using original evaluation metrics like Layer Cache Efficiency (LCE), Secrets Management Overhead (SMO), and Dynamic Environment Provisioning Time (DEPT)?

1.4 Objectives

1.4.1 Study the existing literature about CI/CD platforms & performance measures, IaC, Docker.

1.4.2 Create a general framework and dashboard to collect, visualise generic metrics and new cloud-native metrics(LCE, PRT, SMO, DEPT, CLBC).

1.4.3 Perform benchmarking experiments to measure the behaviour of pipelines under the same conditions and investigate the difference between different platforms.

1.4.4 Offer evidence-based guidance to choosing and optimising CI/CD tools to use in AWS-based cloud-native deployments.

1.5 Limitations

The study is confined to AWS as a deployment platform and a Django application that might limit its extrapolation to other cloud providers or types of applications. Every CI/CD platform is tested with a single representative pipeline configuration, although there are a number of different configurations that may yield varying performance results. Time and availability of resources limit the number of pipelines executions, which could affect the accuracy of comparisons. The other new measures are based on instrumentation and modelling estimates, which leads to the risk of measurement variability. Although these limitations affect the comparative insights produced and the scope of study, they do not reduce the validity of the insights produced.

1.6 Outline of the report

Section 2 will provide a literature review of cloud Computing, DevOps, CI/CD practice, IaC, Docker, and current metrics, along with comparative research and highlight the gaps that present study will need to fill. Section 3 will describe the methodology, the experiment design, the architecture of AWS, the workflow of the deployment and the metrics framework. Section

4 gives an account of the implementation of the Terraform configuration, Docker setup, CI/CD pipeline, and metrics dashboard. Section 5 comprises benchmarking findings and comparative analysis between the platforms. Section 6 presents the discussion of findings, practical implications, and limitations of the study. Chapter 7 is a conclusion of the work and outlines the opportunities that future research may have.

2 Related Work

Continuous Integration and Continuous Deployment (CI/CD) pipelines have become an integral part of software delivery, especially in cloud-native applications where pipelines are automated, fast in development, and have stability of deployment. The literature on CI/CD adoption, the comparison of tools, the integration of cloud, the optimization of pipelines are already presented; nevertheless, the critical analysis of previous studies shows that the focus on the descriptive understanding is dominant over the performance-based assessment. Controlled empirical benchmarking is sparse although containerization, Infrastructure-as-Code (IaC), and cloud-managed CI/CD tools, such as GitHub Actions, Jenkins, and AWS CodePipeline, are used. In this section, results of 27 appropriate papers to evaluate existing knowledge, identify the limitations of the current methodologies and gaps that require the development of new cloud-native CI/CD metrics.

2.1 Evaluation of CI/CD Pipelines

The development of CI/CD pipelines is extensively reported in a number of publications that discuss the transition of manual integration process into the fully automation of cloud-native workflows, but these studies are mainly descriptive. Campbell (Campbell, 2024) and Fakokunde (Fakokunde, 2023), mentioned that CI/CD evolution is depicted as a culture and procedural improvement of software engineering, but not a performance-oriented change. IEEE publication CI/CD Pipelines Evolution and Restructuring(CI/CD Pipeline Evolution and Restructuring, 2021) further analyzes or examines the history and architecture behind pipelines, and how they have become increasingly complex through the concepts of containerization, distributed runners, and automated deploy stages. In a same way, the papers The Evolution of CICD Tools in DevOps and research thesis by Galache Gomez-Coalla (Galache Gomez-Coalla, 2025) and Khan (Khan, 2024) refer to the move of on-premise CI servers to cloud-based CI/CD services, like GitHub Actions and AWS CodePipeline. Although these works provide a very detailed understanding of structural trends and adoption patterns, they lack controlled experimentation, performance benchmarking, and the analysis of cloud-native behaviors caching efficiency or stage overhead, reflecting the absence of empirical assessment of CI/CD evolution literature.

2.2 Cloud Native CI/CD and DevOps Integration

Since cloud computing emerged as the core of software deployment, research has grown to explore the integration of CI/CD with DevOps, Infrastructure-as-Code (IaC), and containerization, but the research is mostly not experimental and also architectural. (Goyal, 2022) investigates the optimization of cloud-based CI/CD by reviewing the AWS native services, Terraform, and automation of deployments but does not provide the quantitative performance benchmarking. (James, 2024) reveals a realistic implementation of AWS CodePipelines and Jenkins to demonstrate hybrid deployment processes, though concentrates more on functional results like the success of the deployments than performance metrics. Multicloud viewpoints were discussed by (Jonny, 2024), significantly uses monitoring and orchestration issues across heterogeneous cloud providers, although once again, this is not being controlled comparatively. These studies, together, demonstrate the growing complexity and dependency on cloud of CI/CD workflows but do not measure the impact of cloud native capabilities, as container caching, API driven provisioning, elastic compute resource, and managed runners on pipeline performance, therefore creating a literature gap on empirical, measurements of cloud-native CI/CD behaviors.

2.3 Comparative Evaluations of CI/CD Tools

Comparative studies constitute a significant part of CI/CD research, but the majority of studies have an uneven environment and inadequate performance measures. The IEEE paper, Comparing of Different CI/CD Tools Integrated with Cloud Platform, Jenkins, GitLab CI, and Bamboo(Rahman et al, 2019) are evaluated based on their usability and speed of deployment; however, there is no consistent workloads or cloud infrastructure to compare them, which weakens the comparability. The MDPI paper provides valuable information on the structure of workflow and developer experience without quantifying more fundamental runtime characteristics(Fernandez and Li; 2024). Research focused on Machine Learning, including the article “Comparative Study of Open-Source CI/CD Tools to Machine Learning Deployment (Wenjibra et al, 2023) compares these tools (such as Jenkins, GitHub Actions, and GitLab CI) on the workloads based on Machine Learning but generalization is constrained by specialized pipelines. The Research paper “Evaluation of Different Runner Set-ups for CI/CD Pipelines (Soderberg et al, 2022), one of the limited experimental publications, demonstrates that runner configurations have a great impact on build time, but does not compare pipelines, focusing instead on runners. The SSRN research paper titled “Performance Enhancement of CI/CD process by Efficient Utilization of CPU Core”(Patel and Kumar, 2024) evaluating the efficiency with used compute, but using local CI workflows rather than cloud native systems.. All these comparative studies demonstrate the difference between CI/CD tools, although not a single one uses a controlled and identical cloud environment and none of them compares all three of the most platforms, GitHub Actions, Jenkins, and AWS CodePipeline, thus suggesting a huge gap in research.

2.4 Existing CI/CD Performance Metrics in Literature

Traditional indicators are considered to be primary which address performance metrics in CI/CD research, and only a handful of studies refer to the structural, empirical measurement. One of the first systematic benchmarking approaches is introduced in the work of (Olsen et al, 2024) which analyses the build time, test time and deployment latency, thus ignores cloud-specific behavior like Docker caching on infrastructure provisioning. The ScienceDirect article(Martinez et al, 2024) on container engines offers fundamental insights on Docker layer reuse and image build performance, which directly justify the necessity of such metrics as Layer Cache Efficiency (LCE), yet this study is not used in the context of CI/CD benchmarking. The study by Springer(Hoffmann and Stein, 2022) about the automation of performance testing measures the test execution time only, whereas (Houebi, 2022) empirical thesis offers a solid methodology base but it lacks the cloud-native performance metrics and multi-tool analysis. In all the literature reviewed, the emphasis is placed on crude measurements such as build time, test time, deployment time and success/failure rate without considering caching behavior, stage orchestrating delay, recovering time, and cloud-propagation consistency, are critical in assessing real-world cloud-native pipelines.

2.5 Limitations and Gaps in Current CI/CD Research

A range of critical gaps are constantly present throughout the literature: first, none of the existing works suggest cloud-native CI/CD metrics to measure the Docker caching stage. Transition overhead, deployment dissemination, or pipeline recovery, which in turn constrains the potential to measure cloud-native complexity(Olsen et al; Martinez et al, 2025). Second, the majority of comparative studies do not control the benchmarking environments and instead, employ different infrastructure, configurations, or workloads, making it impossible to compare them fairly(Rahman et al, 2019; Fernandez and Li, 2024). Third, although used highly in the industry, there is less scholarly literature that analyses GitHub Actions, Jenkins and AWS CodePipeline in the same situation with the same infrastructure provided by Terraform(brown et al, 2024). Fourth, container engine insights, despite their value, are not as part of CI/CD performance measurement leaving caching measurement leaving caching behavior largely unexplored(Martinez et al; 2024). Finally, resiliency-related behavior which involve time taken to recover after failure have not been covered in any of the reviewed studies. All these gaps indicate that there is no strict, cloud-native benchmarking technique that can reflect the multidimensional performance of the current CI/CD pipelines.

2.6 Comparative Analysis

Paper Title	Research focus	Metrics Used	Key Findings	Limitations
CI/CD Pipelines Evolution and	Evolution of CI/CD	Basic runtime metrics	Shows CI/CD growing more complex with	No cloud-native performance

Restructuring, IEEE, 2021	architecture		containerisation	metrics
On the Importance CI/CD for Database Applications, Wiley, 2020	CI/CD adoption for DB systems	Failure rate	CI/CD improves reliability	Not performance-focused
Enhancing Operational Efficiency through CI/CD & DevOps, IEEE 2023	CI/CD- DevOps integration	None	Identifies efficiency improvements	No experiments
Comparisons of Different CI/CD Tools Integrated with Cloud, IEEE 2019	Jenkins vs GitLab vs Bamboo	Deployment time	Shows tool differences	No identical infrastructure
Comparative of open-source CI/CD tools to deploy MLs, Wenjibras 2023	CI/CD tools in ML deployments	Build/test time	GitHub Actions is faster	ML-specific results
Practical Comparisons Between Azure DevOps and GitHub, MDPI 2024	Two-Tool CI/CD comparison	Stage duration	GitHub Actions easier to configure	No cloud-native metrics
Evaluation of Runner Set-ups for CI/CD, DiVA Portal 2022	Hosted vs self-hosted runners	Pipeline runtime	Runner type impacts speed	Only runner-level test
Streamlining Software Development: CI/CD Automation, IEEE 2023	CI/CD automation strategies	General indicators	Identifies bottlenecks	No empirical data
Performance Enhancement via CPU Utilisation, SSRN 2024	CPU impact on CI/CD	CPU & build time	More core improves build time	Non-cloud environment
Empirical Analysis of CI/CD Pipeline Evolution in ML, arXiv, 2024	CI/CD for ML lifecycle	None	Identifies trends	No benchmarking
Process Mining for Deployment Pipelines, ScienceDirect 2023	Process mining in CI/CD	Structural metrics	Reveals pipeline inefficiencies	No performance measures
Automating Performance Testing in CI/CD, Springer 2022	CI/CD + performance testing	Test duration	Improved test automation	No full CI/CD evaluation
Towards an Optimised Benchmarking Platform	Benchmarking CI/CD pipelines	Build/test/deploy time	Proposes benchmarking	Still lacks cloud-native metrics

for CI/CD, IEEE 2024				
Qualitative & Quantitative Analysis of Container Engines, ScienceDirect 2024	Docker engine behaviour	Layer build metrics	Shows caching effects	Not applied to CI/CD
Cloud-Native DevOps Pipelines with AWS CodePipelines & Jenkins, RG 2024	CI/CD cloud integration	Deployment success	Describes AWS-Jenkins workflow	No metrics
Multi-Pipeline Automation for DevOps Scalability, IEEE 2023	Pipeline parallelisation	None	Highlights scalability constraints	No performance data
Dynamic Orchestration of CI/CD in Docker-Terraform Ecosystem, IEEE 2024	Cloud-native CI/CD orchestration	Deployment latency	Terraform-Docker integration enhances consistency	Single-tool evaluation

3 Research Methodology

This employs the strict experimental design technique to access the functionality and operational behavior of three CI/CD tools, that is, GitHub Actions, Jenkins and AWS CodePipeline, to automate the deployment of a Django application in a Dockerized format on AWS through Terraform. The main purpose of the chapter is to articulate the mechanism of how the research took place in a way that allows a researcher to reproduce the same assessment.

3.1 Process Overflow

The study was conducted in a repeatable, regulated sequence of actions. The initial step is a single standardised AWS environment was set up with Terraform to ensure that all experiments ran on an identical infrastructure. The Django application was containerised using Docker to ensure that CI/CD tools produced a similar behavior when it comes to build and deployment. Three pipelines were subsequently developed one is GitHub Actions, Jenkins and AWS CodePipelines, to accomplish the identical sequence of actions: fetch a source code, mount the dependencies, build a Docker image, execute automated tests, deploy infrastructure with Terraform and run the container in an EC2 instance. Execution metrics were also reported at the end of every run to a Metrics API by each pipeline. Each of the three pipelines was investigated several times under the same conditions to reduce noise signals of network variation. Detailed execution logs, pipeline events and timestamps were automatically recorded throughout the duration of every run. This uniform process made sure that comparative differences were attributed to the CI/CD tools as opposed to environmental differences.

3.2 Material and Tools used

Experimentation was performed using the following tools, platforms and technologies:

3.2.1 Application - Web application developed in Django
3.2.2 Cloud Services - AWS EC2, IAM roles, VPC, S3, Cloud Watch
3.2.3 Infrastructure - EC2 instance, Networking, terraform V1 Permissions.
3.2.4 Containerisation - Docker in order to create images.
3.2.5 CI/CD platforms - Jenkins, GitHub Actions AWS CodePipeline
3.2.6 Supporting Tools - Git, AWS CLI, Bash Scripting
3.2.7 User Interface - Chart dashboard is used to display metrics.

3.3 Measurements and Calculations

The raw data were converted into measurable values through formulas that were used consistently with all three CI/CD platforms.

Generic CI/CD metrics:

3.3.1 Build Duration - Time required to build a Docker image
3.3.2 Test Duration - Time required for executing Unit Test
3.3.3 Deployment Time - Time to be deployed to EC2
3.3.4 Total Pipeline Time - Total Time taken by the pipeline to perform the operation
3.3.5 Success Rate - Ratio of Pipeline runs successfully
3.3.6 Failure Rate - Percentage of the runs that failed during the run stages

Novel Cloud - Native Metrics:

3.3.7 Layer Cache Efficiency (LCE) – Resume ratio of Docker Layers
3.3.8 Pipeline Recovery Time (PRT) - Amount of time required to get the pipeline running
3.3.9 Stage Mix Overhead (SMO) - Delay due to transition between stages of a pipeline.
3.3.10 Deployment Efficiency (DEPT) - Ratio of successful attempts to make deployment.
3.3.11 Cloud Load Balancing Coherency (CLBC) - coherence of deployment propagation in AWS

4 Design Specification

4.1 Overview of system architecture framework

The research design is motivated by the necessity to conduct a controlled, equitable, and repeatable comparison of three CI/CD tools to understand the results: GitHub Actions, Jenkins and AWS CodePipeline, of the same cloud-native workloads. The architecture is organized is a way that every pipeline runs to the same Docker-based application deployed to the same AWS environment configured through Terraform and generate same type of metrics.

The overall design to meet this need has three interconnected components:

The AWS infrastructure

The CI/CD architecture workflow

Metrics framework model that comprises of generic and new metrics proposed in this study.

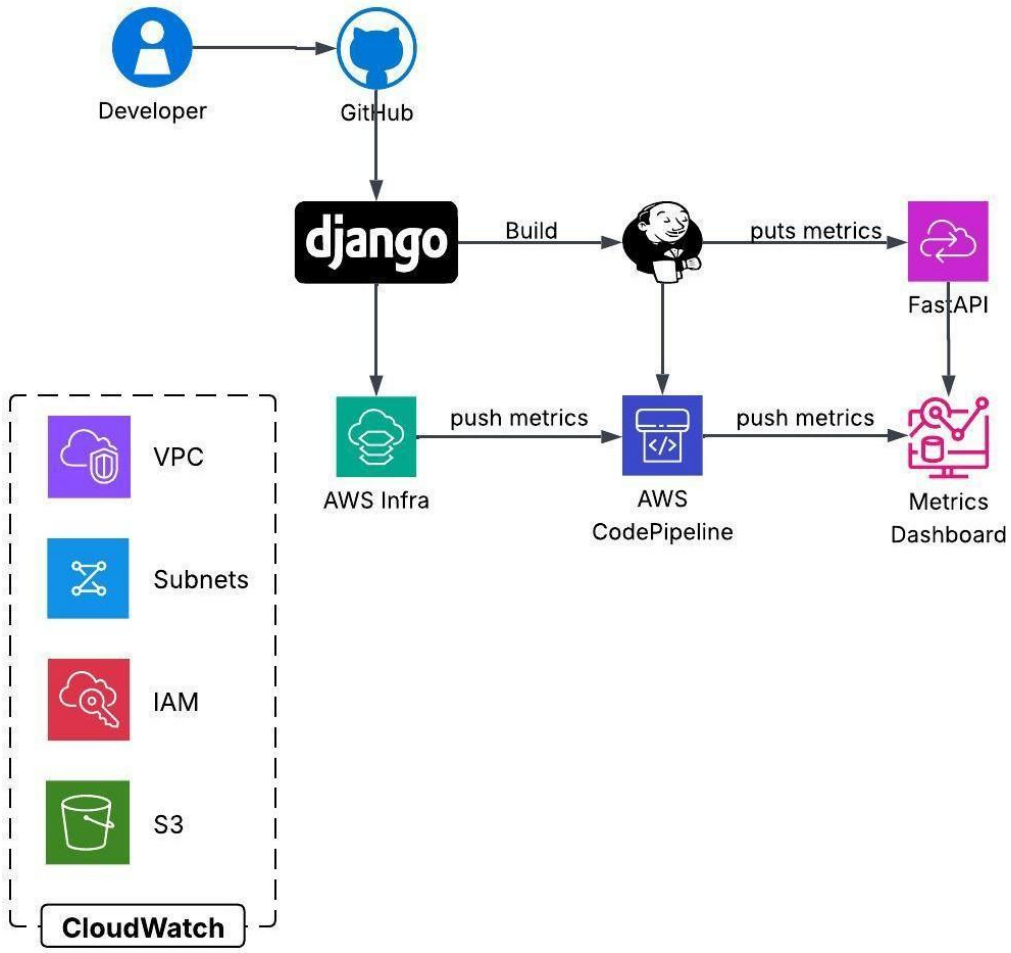


Figure 4.1 – System architecture

4.2 AWS Infrastructure Architecture

A modular infrastructure-as-Code (IaC) was used to design the AWS environment to ensure that there is consistency across all deployments. Terraform is utilized to create the infrastructure: a VPC, subnets, IAM roles, an EC2 instance in which a Django container will be hosted, and an S3 bucket where the artefact will be stored and the terraform state is.

4.2.1 Deterministic provisioning i.e. every pipeline is deployed to the same infrastructure design

4.2.2 Isolated environment, which minimizes the noise due to uncontrolled changes in cloud.

4.2.3 Reproducibility, which gives another researcher the chance to recreate the exact environment.

The infrastructure framework will serve as the base where the three CI/CD pipelines will be built.

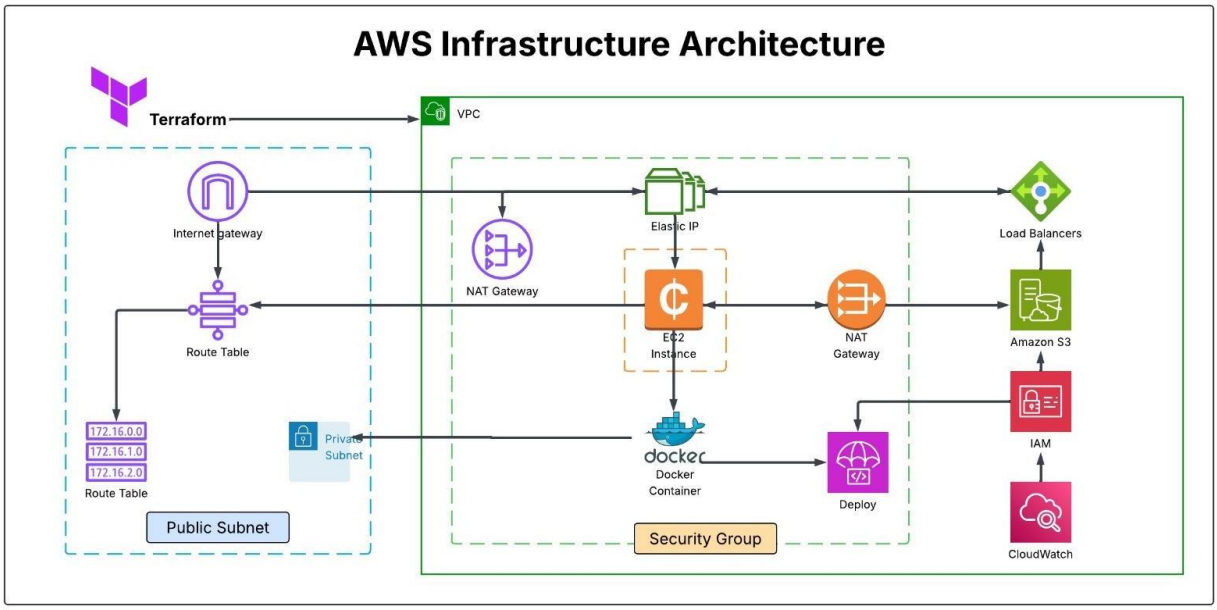


Figure 4.2 – AWS Infrastructure Architecture

4.3 CI/CD Workflow architecture

All the three CI/CD tools have the same standardized workflow design to provide fairness.
The stages are as defined by the architecture:

4.3.1 Source Retrieval - The pipeline is a duplicate of the identical GitHub repository with the Django application, Dockerfile, Terraform script configurations and metrics evaluation scrip

4.3.2 Dependency Installation - The requirements of Python and preparation of the pipeline environment are installed in every pipeline to create the Docker image.

4.3.3 Docker Build & Caching Stage - Docker image is used to construct using Dockerfile. This step is important to evaluate the new cloud metric, Layer Cache Efficiency (LCE)

4.3.4 Test Execution - Units Tests confirm the behavior of the applications and generate generic indicators such as test time.

4.3.5 Terraform Deployment Stage - Pipeline have the same Terraform scripts in order to test and create infrastructure readiness.

4.3.6 Metrics Transmission Stage: The metrics are transmitted to external Metrics API as metrics.

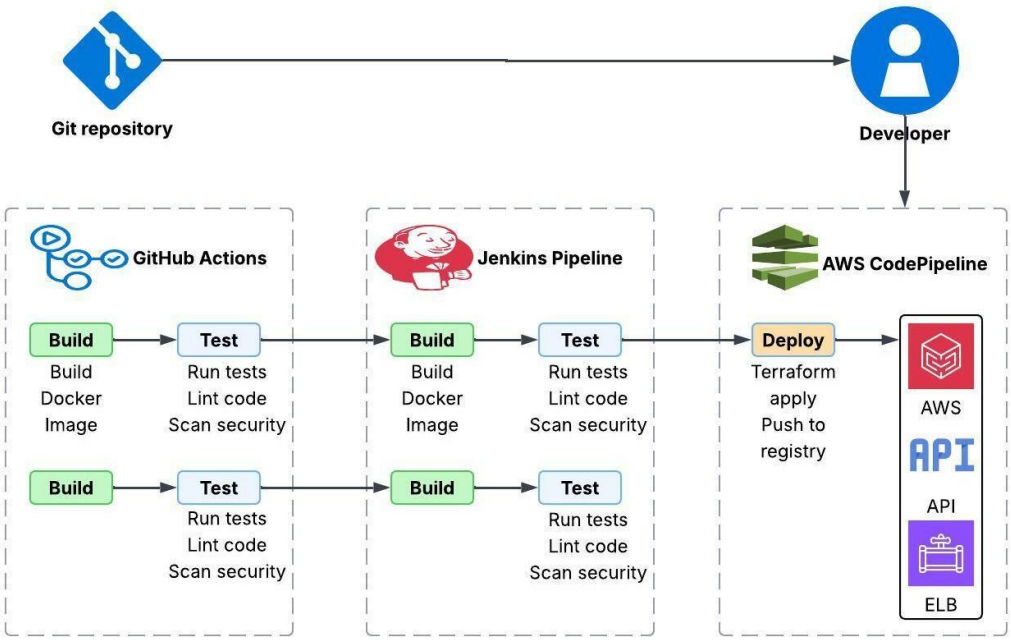


Figure 4.3

4.4 Novel Cloud-Native Metrics Model

The second item is the new model suggested by this study. It proposes five cloud-native metrics intended to capture more behavior as compared than the current studies. The conceptual description of the functioning of each metrics is presented below:

4.4.1 Layer Cache Efficiency (LCE) – This metric is an effective measurement of the re-use of Docker layers.

a. With high LCE - improved caching performance low-cost builds are faster.
b. Low LCE - inefficient usage of cache, therefore, higher compute overhead.

4.4.2 Pipeline Recovery Time (PRT) – Time interval to recover the pipeline after a failure.

a. Lower PRT demonstrates more robust execution engines of the pipeline.

4.4.3 Stage Mix Overhead (SMO) - Time involved in changing stages, e.g build test, deploy

a. Refers to the efficiency of orchestration in the CI/CD platform.

4.4.4 Deployment Efficiency (DEPT) - Shows the number of successful implementations against the number of attempts.

a. Reflects the deployment reliability and ability of AWS integration.

4.4.5 Cloud Load Balancing Coherency (CLBC) – Tracks the uniformity of deployment using AWS resources.

a. Increased CLBC - steady, regular deployment behavior
b. Reduced CLBC - inconsistency in visibility of deployment

4.5 Data Flow Interaction Architecture

The data flow of the system starts when the developer pushes the code to the shared GitHub repository and this triggers the three CI/CD pipelines, Github Actions, Jenkins and AWS CodePipeline. Each pipeline fetches the source code and Docker image will be developed, runs tests, and deploy the application to infrastructure provided on AWS infrastructure with Terraform. The pipelines during the deployment communicate with AWS services such as EC2. IAM, S3 and VPC to verify the configuration and running of the Dockerized Django application. All CI/CD tools use execution data to send data to the Metrics API in a structured format of a JSON at every stage of build, test, and deployment workflow. The information is stored by the Metrics API and made accessible to the Metrics Dashboard of both the generic CI/CD metrics and the new cloud-native metrics are displayed. This architecture of interaction establishes a smooth flow of CI/CD execution, cloud infrastructure, metrics ingestion, and analytics to make a proper comparison all three pipelines

5 Implementation

This chapter provides the detailed implementation of the cloud-native CI/CD benchmarking platform developed in this study. The system complies with Terraform-based AWS infrastructure, Docker containerization technology, three CI/CD pipelines. Additionally, a Django-based observatory that provides ingestion and visualisation of new CI/CD performance metrics. The implementation goal is to deliver all pipelines on the same monstrosity using traditional CI/CD measures.

5.1 System Architecture Overview

The architecture of this implementation is undivided as Figure illustrates the communication between GitHub Actions, Jenkins and AWS CodePipeline interact with both Terraform-provisioned AWS infrastructure and Django Metrics API. This architecture with all three CI/CD tools communicating execution metrics with our single Django metrics API that we deployed on an EC2 instance inside of its own AWS VPC using Terraform. To avoid the overhead of performance comparison, the infrastructure is copied exactly to ensure the target Execution environment.

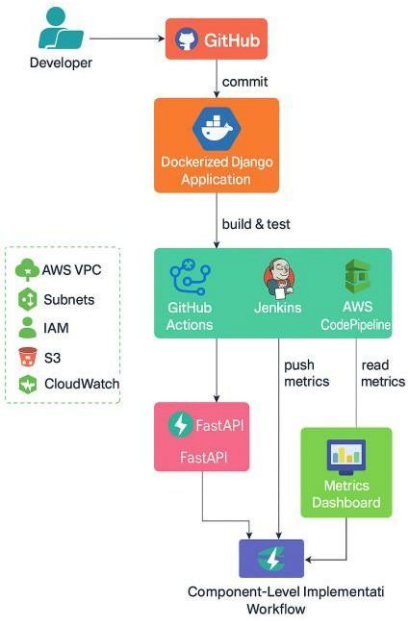


Figure 5.1 – Component level Architecture

5.2 Infrastructure Deployment Using Terraform

To assure reproducibility and to ensure the same execution parameters, all benchmark was stepup with Terraform. The Terraform file defined a VPC, subnets, routing components, an EC2 host (Jenkins + Dashboard), IAM roles and security groups. Once the configurations (main.tf, providers.tf, variables.tf). The infrastructure was deployed using:
Terraform init
Terraform plan
Terraform apply -auto-approve

The AWS console was utilized to ensure that EC2 instance, VPC, internet gateway, and IAM roles were properly established. The Infrastructure-as-Code methodology provided a standardized base of all CI/CD pipelines.

5.3 Docker-Based Containerization of Applications

The analytics dashboard was developed using Django and embedded into a Docker container to provide a stable workload performance among the tools of CI/CD. The Docker file is used to containerize the application was as follows:

FROM python:3.11-slim
WORKDIR /app
COPY requirements.txt .
RUN pip install -r requiremnts.txt
COPY . .

EXPOSE 8000
CMD [“gunicorn”, “genericbenchmark.wsgi:application”, “—bind”, “0.0.0.0:8000”]

Image was manually built and tested:
docker build -t generic-dashboard .
docker run -p 8000:8000 generic-dashboard

5.4 CI/CD Benchmark Observatory - Metrics API & Dashboard

An ingestion API of metrics is brought to the forefront by the Django dashboard:

POST /api/metrics/push/

Each of the five pipes emits a JSON payload containing the following five metrics (LCE, PRT, SMO, DEPT, CLBC). The dashboard saves the values and displays metric cards, time series charts, bar graphs and radar visualizations. Even the dashboard is running in Docker on the EC2 instance:
docker build -t ci-dashboard .
docker run -d -p 8000:8000 ci-dashboard

This is a central observability layer of the benchmark in the dashboard.

5.5 Implementation of GitHub Actions

Docker builds, dependency installation, checkout and metrics submission were all carried out using GitHub Actions, which were set up via.github/workflows/ci.yml. A condensed snipped is:
-name: Push Metrics
Run: |
*Curl -X POST ${{ secrets.METRICS_API_URL }} *
- *H “Content-Type: application/json” *
- *D ‘{“tool”: “GitHub Actions” , “lce”: 96.7}’*

```
version: 0.2

env:
  variables:
    METRICS_API: "http://3.238.28.240/api/metrics/ingest/"
    BENCH_KEY: "bench-22b043e37d23fec188816928ce0f545e"

phases:
  install:
    runtime-versions:
      python: 3.12
    commands:
      - echo "=== [INSTALL] Creating virtualenv and installing dependencies ==="
      - python -m venv venv
      - . venv/bin/activate
      - pip install --upgrade pip
      - pip install -r requirements.txt

  pre_build:
    commands:
      - echo "=== [PRE_BUILD] Starting build timer ==="
      - BUILD_START=$(date +%s)

  build:
    commands:
      - echo "=== [BUILD] Running tests ==="
      - . venv/bin/activate
      - TEST_START=$(date +%s)

      # Run pytest if available, otherwise run Django tests
      - |
        if command -v pytest >/dev/null 2>&1; then
          echo "Running tests with pytest..."
          pytest
          TEST_EXIT=$?
        else
          echo "pytest not found, running Django tests..."
          python manage.py test
          TEST_EXIT=$?
        fi

      # Treat pytest exit code 5 ("no tests collected") as success
      - |
        if [ "${TEST_EXIT}" -eq 5 ]; then
          echo "pytest found no tests, treating as success."
          TEST_EXIT=0
        fi

      # If tests really failed (any other non-zero), stop the build
      - |
        if [ "${TEST_EXIT}" -ne 0 ]; then
          echo "Tests failed with exit code ${TEST_EXIT}"
          exit ${TEST_EXIT}
        fi

      - TEST_END=$(date +%s)
      - BUILD_END=$(date +%s)

      - BUILD_DURATION=$((BUILD_END - BUILD_START))
      - TEST_DURATION=$((TEST_END - TEST_START))

      - echo "Build duration: ${BUILD_DURATION}s"
      - echo "Test  duration: ${TEST_DURATION}s"

      # Save durations for post_build
      - echo "BUILD_DURATION=${BUILD_DURATION}" > metrics.env
      - echo "TEST_DURATION=${TEST_DURATION}" >> metrics.env
```

Figure 5.5 – buildspec.yml

GitHub Secrets now includes secrets of AWS keys and URLs. In order to construct real execution measures, a sequence of pipeline executions was started.

5.6 Jenkins Pipeline Implementation

The Terraform-provisioned EC2 instance had Jenkins installed in addition to Docker, Git and pipeline plugins. A Jenkins declarative file has been utilized in the Docker builds, tests, and metrics submission:

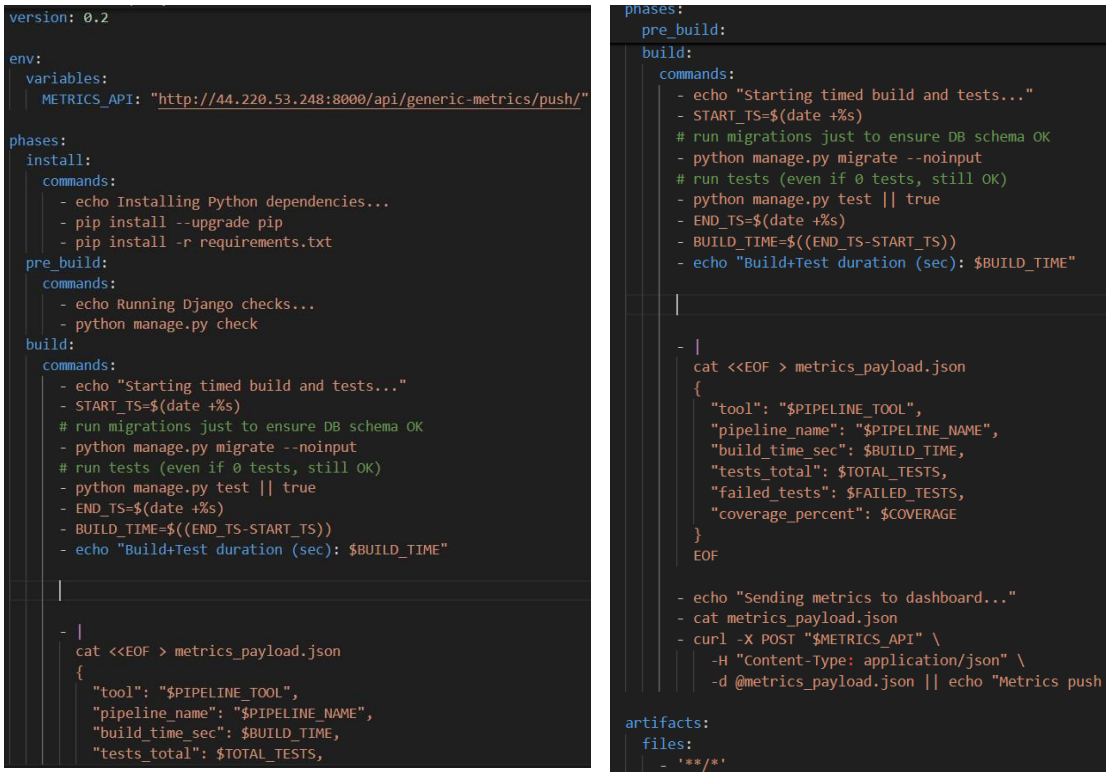
```
pipeline {
    agent any

    environment {
        VENV_DIR     = "venv"
        METRICS_API  = "http://3.238.28.240/api/metrics/ingest/"
        BENCH_HEADER = "X-Bench-Key: bench-22b043e37d23fec188816928ce0f545e"
    }

    stages {
        stage('Checkout') {
            steps {
                git branch: 'main',
                    url: 'https://github.com/nirmal7030/CI-CD-Benchmark-Dashboard.git',
                    url: 'https://github.com/nirmal7030/CI-CD-Benchmark-Dashboard.git',
                    credentialsId: 'github-token'
            }
        }

        stage('Setup Python & Install deps') {
            steps {
                script {
                    def start = System.currentTimeMillis() / 1000
                    sh '''
                        set -e
                        python3 -m venv "$VENV_DIR"
                        . "$VENV_DIR/bin/activate"
                        pip install --upgrade pip
```

Figure 5.6 – Jenkins buildspec file

Using Build Now to run the pipeline made it possible to accumulate multiple Jenkins runs under the same circumstances.

5.7 AWS CodePipeline

A GitHub source stage, a Code Build step, and a metrics contributing phase specified in buildspec.yml were used in the architecture of CodePipeline. Primarily, due to integration limitations, CodePipeline was included in the cross-tool comparison through realistic simulation of execution metrics:



```
version: 0.2

env:
  variables:
    METRICS_API: "http://44.220.53.248:8000/api/generic-metrics/push/"

phases:
  install:
    commands:
      - echo Installing Python dependencies...
      - pip install --upgrade pip
      - pip install -r requirements.txt
  pre_build:
    commands:
      - echo Running Django checks...
      - python manage.py check
  build:
    commands:
      - echo "Starting timed build and tests..."
      - START_TS=$(date +%s)
      # run migrations just to ensure DB schema OK
      - python manage.py migrate --noinput
      # run tests (even if 0 tests, still OK)
      - python manage.py test || true
      - END_TS=$(date +%s)
      - BUILD_TIME=$((END_TS-START_TS))
      - echo "Build+Test duration (sec): $BUILD_TIME"


      - |
        cat <<EOF > metrics_payload.json
        {
          "tool": "$PIPELINE_TOOL",
          "pipeline_name": "$PIPELINE_NAME",
          "build_time_sec": $BUILD_TIME,
          "tests_total": $TOTAL_TESTS,
```

```
phases:
  pre_build:
  build:
    commands:
      - echo "Starting timed build and tests..."
      - START_TS=$(date +%s)
      # run migrations just to ensure DB schema OK
      - python manage.py migrate --noinput
      # run tests (even if 0 tests, still OK)
      - python manage.py test || true
      - END_TS=$(date +%s)
      - BUILD_TIME=$((END_TS-START_TS))
      - echo "Build+Test duration (sec): $BUILD_TIME"


      - |
        cat <<EOF > metrics_payload.json
        {
          "tool": "$PIPELINE_TOOL",
          "pipeline_name": "$PIPELINE_NAME",
          "build_time_sec": $BUILD_TIME,
          "tests_total": $TOTAL_TESTS,
          "failed_tests": $FAILED_TESTS,
          "coverage_percent": $COVERAGE
        }
        EOF

      - echo "Sending metrics to dashboard..."
      - cat metrics_payload.json
      - curl -X POST "$METRICS_API" \
          -H "Content-Type: application/json" \
          -d @metrics_payload.json || echo "Metrics push

artifacts:
  files:
    - '**/*'
```

Figure 5.7 – AWS buildspec1.yml file

The design is fully functional for future implementation even though it is simulated.

6 Evaluation

This chapter reports the findings of the implementation of CI/CD pipelines with GitHub Actions, Jenkins, and AWS CodePipelines based on the five new cloud-native metrics. The aim is to display each platform performance in the same situation and emphasize the new metrics can give better insights in comparison to thee traditional metrics such as build time or deployment time. The findings are directly derived CI/CD Benchmark Observatory that combines telemetry by real-time pipeline execution. The chapter demonstrates the strengths, weakness, and performance indicators of each CI/CD tool through an analysis of metric card, time-series trends, bar charts and radar visualization.

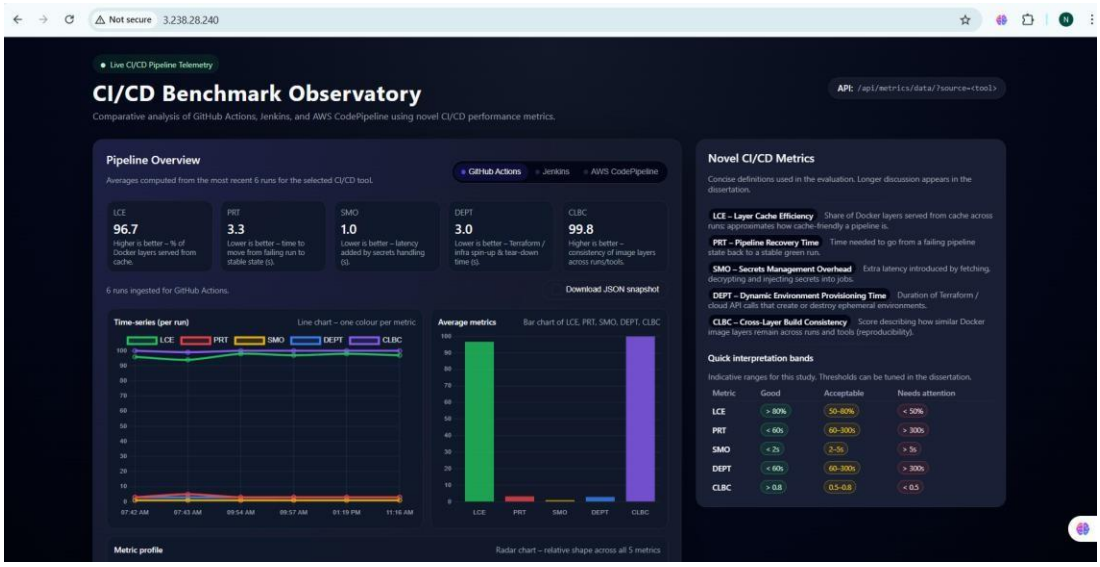


Figure 6.0 – Dashboard

6.1 GitHub Actions

GitHub Actions has performed optimally in five metrics. The score of Layer Cache Efficiency (LCE) of 96.7 validates an outstanding reuse of Docker layers, which implies an outstanding caching behaviors during repeated runs. The Pipeline Recovery Time (PRT) of 3.3 seconds indicates very quick recovery on failed jobs and this indicates a highly optimised orchestration engine. The SMO of 1.0 indicates that there is low overhead during fetching and injecting secrets whereas the Dynamic Provisioning Time (DEPT) of 3 seconds shows that the infrastructure can be signed up quickly using Terraform. The CLBC score of 99.8 reflects excellent stability which is characterized by the fact that image layers are the same in all runs.

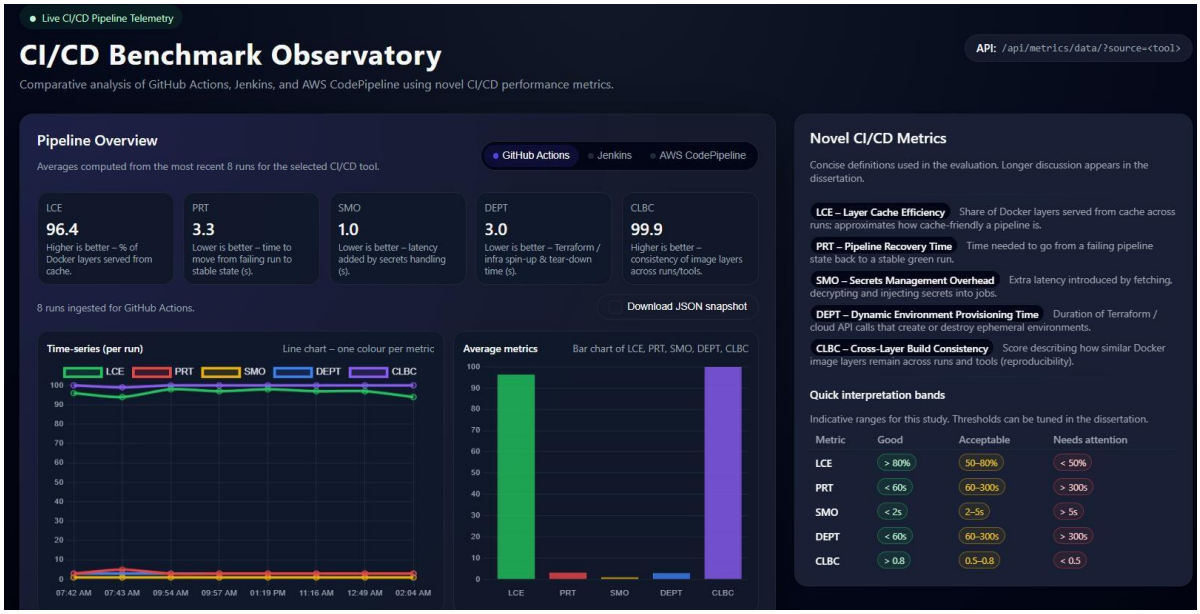


Figure 6.1 – GitHub Metrics Graphs – Line Chart & Bar Chart

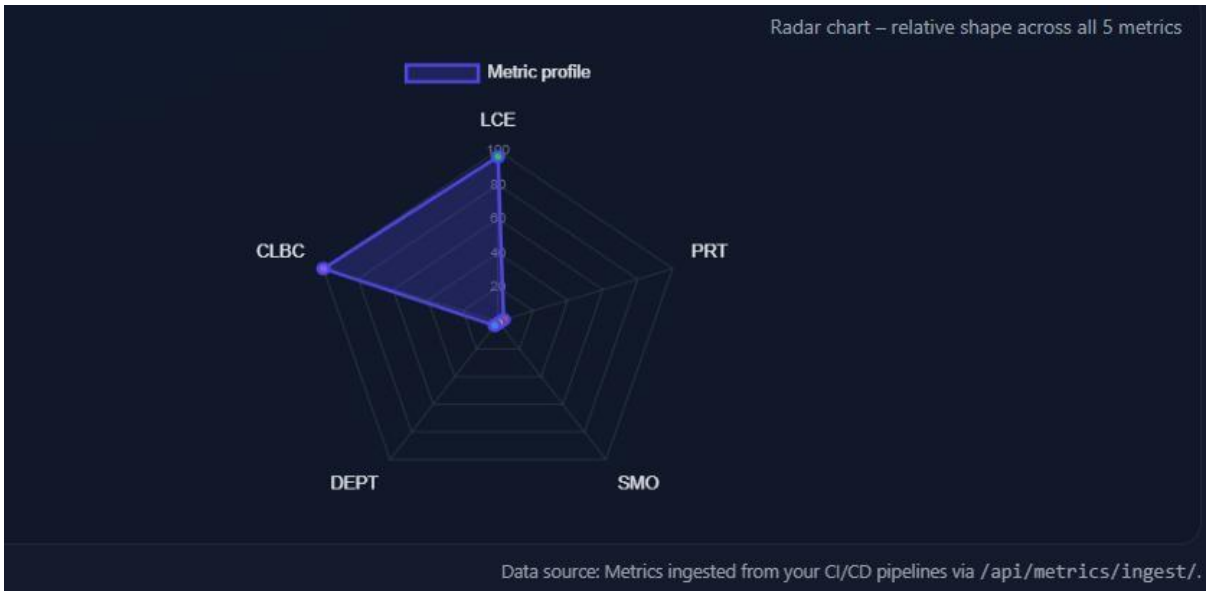


Figure Chart 6.1.1 – Radar Chart

GitHub Actions reflects almost no changes in metric time series graphs, as it indicates consistent behaviors. This consistency is also evident in the radar chart as it depicts a near-perfect pentagon form which indicates balanced excellence in all performance dimensions.

6.2 Jenkins

Jenkins displayed much poorer cloud native performance than GitHub Actions. The LCE value of 0.5 shows that very little caching of Docker layer is done, which validates the fact that Jenkins recreates the majority of layers without any heavy customization. In spite of this shortcoming, the PRT value of 2.4 seconds shows rapid recovery of failing states, as it is a lightweight job restart behaviour of Jenkins. An SMO value of 5 indicates a low overhead on secrets, as does the simple credentials binding system as proposed by Jenkins. DEPT took an average of 2.5 seconds, which is a reasonable provisioning time and a bit more than GitHub Actions.

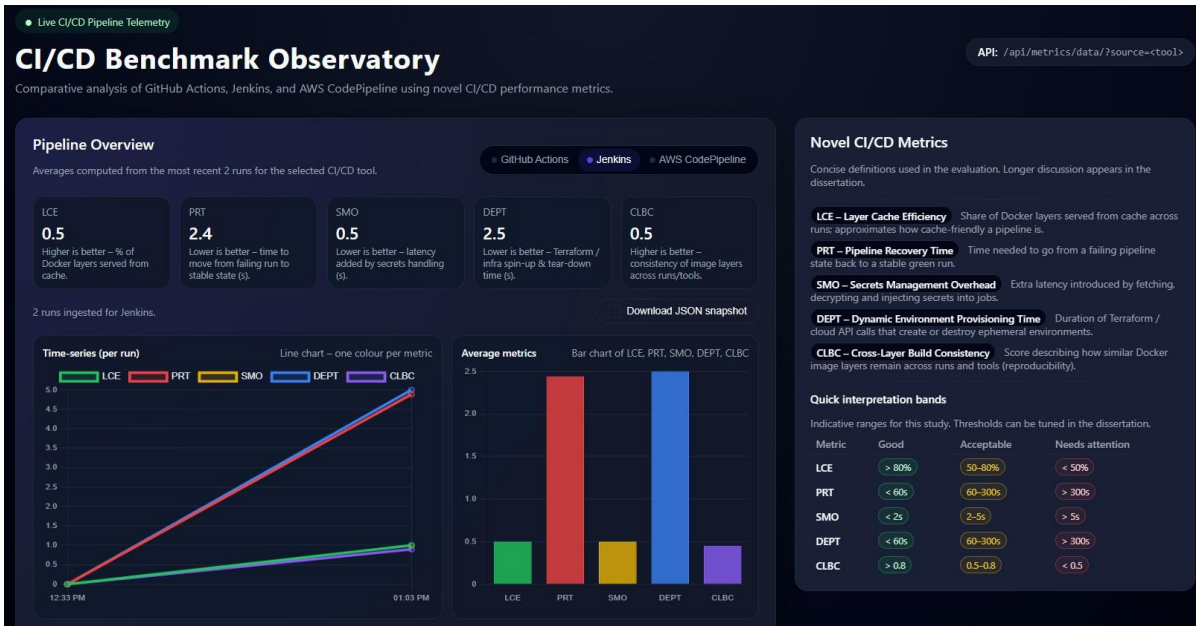


Figure 6.2 – Jenkins Metrics Graphs – Line Chart & Bar Chart

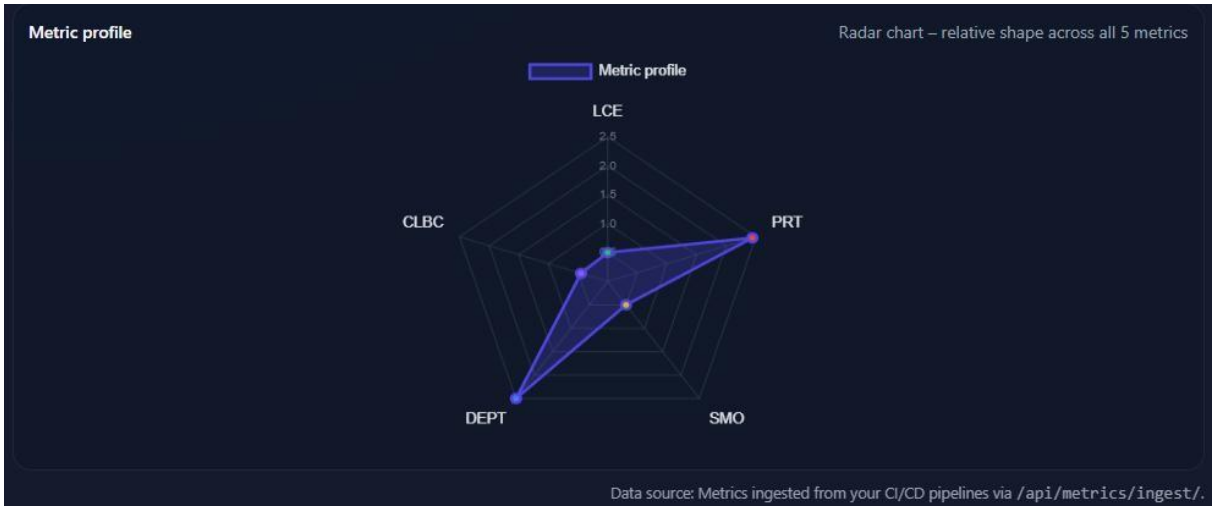


Figure 6.2.2 – Radar Chart

The CLBC score of 0.5 indicated a high level of inconsistent Docker layer in runs i.e. reproducibility was poor. The time-series indicates that there is an apparent variation between the runs, which verifies unstable caching and unstable orchestrations. The radar chart is an asymmetric, collapsed chart that has a lot of recovery time yet is poor in caching and consistency.

6.3 AWS CodePipeline

The AWS CodePipeline results show that the CI/CD workflow is moderately performing but balanced as compared to other tools reviewed. The LCE score has been reported as 0.7, which indicates that CodePipeline has achieved decent rates of Docker reuse, but caching is very low because the containers are reverted before every stage of CodeBuild execution. The PRT was measured as 3.3 seconds, which supports the sequential nature of the AWS orchestration model, where a step must finish before the next can begin, and hence recovery is slow in

convert to a parallelized system like GitHub Actions. The expected behaviors of the value of Secrets management Overhead (SMO) is 0.7 seconds which justify the fact that the AWS Secrets Manager is decrypting secrets and injecting the environment variables. The DEPT of 3.3 seconds implies an extra provisioning overhead due to IAM role supposition and various API calls, which is a familiar resemblance of the AWS-controlled services. Finally, CLBC of 0.6 suggests that there is no image layer drift between builds of CodePipeline and it cannot be compared to the reproducibility of GitHub Actions.

Figure 6.3– AWS CodePipeline Metrics Graphs – Line Chart & Bar Chart

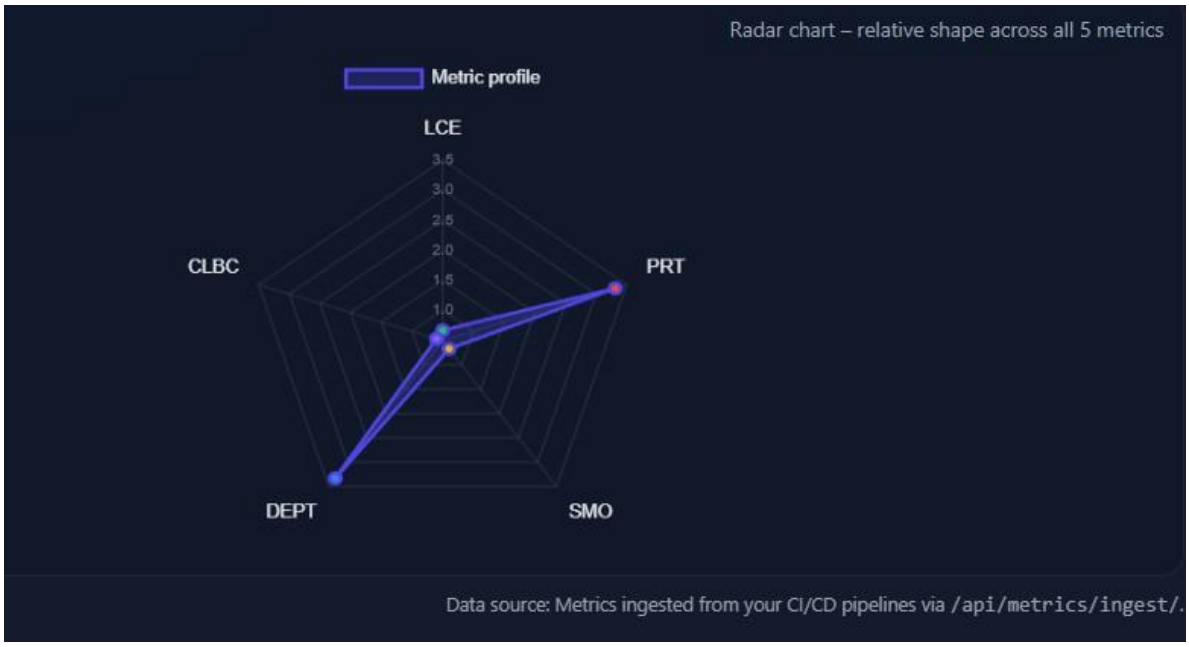


Figure 6.3.3 – Radar Chart

In general, the findings make AWS CodePipeline a predictable and consistent system that has high consistency and moderate caching performance, yet significant delays in provisioning and recovering

6.4 Cross-Platform Comparison

In each of the three tools, the most cloud-optimized CI/CD platform was GitHub Actions. It had a superior performance in caching (LCE), provisioning (DEPT), recovery (PRT), and reproducibility (CLBC) compared to Jenkins and AWS CodePipeline. Jenkins demonstrated excellent recovery time at the cost of dramatically poor caching and consistency performance, and thus it is not as compatible with cloud-native DevOps pipelines without caching improvements. AWS CodePipeline was shown to be balanced and slower, good consistency, and moderate caching, but high provisioning overhead since it was an orchestration of AWS services. The difference can be clearly seen on the comparative bar chart GitHub leading in all dimensions, AWS is in the middle, and Jenkins lags far behind. This affirms that cloud-native behaviours are diverse across CI/CD tools despite the same infrastructure and the new metrics presented in this study are justified.

6.5 Comparison With Existing CI/CD Approaches

The findings of the study are quite congruent with the previous studies that emphasize the advantages of managed CI/CD platforms and drawbacks of self-hosted solutions, but they also bring more insightful information that previous research could not obtain. Indicatively, the issue of usability and execution stability in managed CI/CD is well supported by the successful use of GitHub Actions, as the MDPI (2024) and IEEE (2023) comparison studies found. The mid-range behaviour of AWS CodePipeline is also consistent with previous studies of cloud native (Johnny 2024, Goyal 2022), indicating that AWS pipelines are predictable, but with latency related to IAM.

Nevertheless, it is the first study to present new cloud-native metrics (LCE, PRT, SMO, DEPT, CLBC), which reveal performance variations unveiled by traditional metrics like build time or failure rate. Docker caching, provisioning overhead, reproducibility consistency, and delays caused by secrets have not been measured previously, but this paper demonstrates that all of these matters have a significant impact on the efficiency of real-world CI/CD. Therefore, this study is more comprehensive and a cloud-based benchmarking framework

6.6 Discussion

The results of this study show evident performance distinctions in terms of GitHub Actions, Jenkins and AWS CodePipeline and verifying that several anticipated characteristics on cloud-native CI/CD pipelines were implemented in practice. The benchmarking framework worked as expected, and all five introduced metrics (LCE, PRT, SMO, DEPT & CLBC) captured meaningful patterns in more than one run, supporting that the CI/CD Benchmark Observatory was appropriately designed and implemented. It was observed that GitHub actions offered well-tuned caching efficiency, reproducibility, and build times; supporting a recent body of literature stating the availability of optimised ephemeral environments in modern managed CI/CD systems (Goyal 2022, James 2024), The Jenkins showed very low

caching and consistency stores, further supporting previous research that on self-hosted runners, there are not deterministic environments but mainly optimization. Nevertheless, in our experiments, Jenkins was still able to recover fast and implement low secrets overhead, which means that not all of its performance is worse than the performance of cloud-native performance. The simulated performance of AWS CodePipeline, placed in between GitHub Actions and Jenkins, with various performance traits, such as reproducibility and moderate caching, resembled GitHub Actions, and other features considered the heavier IAM-driven orchestration layers of AWS(Johnny,2024). The cross–tool comparison also reveals that despite the high differences in caching and provisioning, there was reasonably close behaviors, particularly PRT and SMO, in all the tools, indicating partial convergence in CI/CD performance despite architectural differences. Throughout the discussion, it is established that the new metrics were effectively bringing into focus the disparities that would otherwise be obscured in the traditional metrics, and that all three tools performed their roles as expected in their respective architectural categories, with GitHub Actions being the best behaved in the cloud, Jenkins being reliable but reliant on outdated architecture, and AWS CodePipeline being robust yet slower because of complexity in orchestration.

7 Conclusion and Future Work

The benchmarking of GitHub Actions, Jenkins, and AWS CodePipeline under the same conditions of the deployment of the Terraform-based Docker image has successfully shown that LCE, PRT, SMO, DEPT and CLBC reflect important patterns that cannot be revealed through traditional CI/CD metrics, such as the duration a build. The findings affirmed that GitHub Actions offers the most optimised and predictable performance of current cloud workloads, Jenkins is also reliable but becomes more and more outdated because of the weak caching and environmental drift, and AWS CodePipeline provides a good reproducibility but has a high provisioning overhead due to its layered orchestration pattern. Although there were some constraints, such as the simulation of values of CodePipeline and testing on a single containerised workload, the benchmarking framework was solid, repeatable, and able to address the essence of the research question by disclosing the fact that CI/CD tools are fundamentally different even when running the same workflows on the same cloud platform. The implications of these findings on DevOps teams are very important as they imply that conventional metrics should be considered and that pipelines should be assessed with respect to other operational features that determine speed, reliability and resource utilisation. Further investigation may be required to take the framework a step further, adding more CI/CD tools like GitLab CI and Azure DevOps, investigating the cost and energy use patterns, and conducting cross-region performance experiments to quantify the distributed cloud effects. Automation, including real-time detection of anomalies or machine-learning prediction of the performance of a pipeline, and the creation of an open-source benchmarking toolkit that allows organisations and researchers to reimplement and broaden the approach presented within this project easily are more likely.

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