Deployment of a Three-Tier Web-Application Using DevSecOps

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Abstract

The paradigm shift from monolithic deployments to microservices, containers, and cloud-native systems has fundamentally altered how modern applications are developed and managed. This paper introduces the Wanderlust Mega Project, a three-tier web application engineered using advanced DevSecOps practices to facilitate continuous integration, delivery, and security. Designed specifically for the dynamic nature of the travel industry, the project leverages Kubernetes-based orchestration, Infrastructure as Code (IaC), automated security testing, and container optimization to build a robust, scalable, and secure environment. This work evaluates the project's design, architecture, implementation, and performance analysis. The inclusion of AI-based observability, blue-green deployment, and chaos testing ensures operational resilience and long-term viability. The findings serve as a case study for integrating DevSecOps in complex software development environments.

Keywords— DevSecOps, CI/CD, Cloud Infrastructure, Kubernetes, Docker, Terraform, Infrastructure as Code, OWASP, Monitoring, Observability, Security Automation

I. INTRODUCTION

1.1 Context and Motivation

The digital landscape continues to evolve rapidly, driven by rising user demands, shortened release cycles, and an increasing need for secure, scalable systems. Traditional Software Development Life Cycles (SDLC), though reliable in structured environments, often struggle to meet these modern expectations. Manual deployments, delayed feedback loops, and the lack of integration between development and operations lead to bottlenecks, reduced productivity, and compromised software quality.

The travel and tourism sector, characterized by dynamic pricing models, personalized itineraries, and real-time booking systems, requires high availability and rapid scalability. System downtime or latency can directly impact user trust and revenue. As applications grow more complex and decentralized, the need for automated, secure, and resilient deployment strategies becomes paramount. DevSecOps offers a promising solution by embedding security within every phase of the software pipeline—from planning to post-deployment monitoring.

This paper focuses on the development and deployment of a three-tier web application for the Wanderlust Mega Project using DevSecOps principles. The solution emphasizes real-time monitoring, security-first development, and automated deployments within a Kubernetes-based cloud environment.

1.2 Project Objectives

The key goals of this project are as follows:

- **Accelerated Development:** Integrate CI/CD pipelines to enable rapid and automated builds, testing, and deployments.
- **Enhanced Scalability:** Utilize Kubernetes and container-based architectures to auto-scale based on traffic and load.
- **Integrated Security:** Embed tools like OWASP ZAP, SonarQube, and Trivy into the development lifecycle to proactively mitigate risks.
- **Full Observability:** Implement Prometheus, Grafana, and Jaeger for real-time system monitoring and distributed tracing.
- **Cost Optimization:** Leverage auto-scaling and right-sized infrastructure to reduce cloud resource consumption and associated costs.

1.3 Research Contribution

This research contributes a detailed case study on the real-world application of DevSecOps in deploying scalable, resilient applications. It documents:

- Tool selection strategies and pipeline configurations.
- Use of automation in infrastructure provisioning and application deployment.
- Integration of real-time security analysis.
- Performance benchmarks and operational insights.

II. ARCHITECTURE AND METHODOLOGY

2.1 Application Architecture

The application follows a **three-tier architecture** composed of presentation, application, and data layers:

- **Presentation Tier:** Developed using ReactJS, this tier provides a responsive frontend hosted on AWS S3 and distributed globally through Amazon CloudFront CDN.
- **Application Tier:** Composed of Node.js-based microservices for authentication, booking, payments, and reviews. These services are containerized using Docker and orchestrated by Kubernetes.
- **Data Tier:** Data is persistently stored in MongoDB Atlas (NoSQL) and Amazon RDS (relational), allowing the separation of structured transactional data and unstructured user-generated content.

Each microservice is independently deployable and communicates through authenticated RESTful APIs with JWT-based access control. Future iterations aim to replace REST with gRPC for performance optimization in high-throughput scenarios.

2.2 Toolchain and Technology Stack

The project employs a sophisticated toolchain to support the full DevSecOps lifecycle:

- **CI/CD:** GitHub Actions for event-driven workflows; Jenkins for advanced pipeline customization.
- **Security Scanning:** OWASP ZAP for dynamic scans, Trivy for container vulnerability checks, and SonarQube for static code analysis.
- **IaC:** Terraform modules provision AWS infrastructure across dev, staging, and prod environments. Configurations are version-controlled in Git.
- **Containerization:** Multi-stage Docker builds reduce image size and security attack surface.
- **Orchestration:** Kubernetes clusters deployed using EKS with auto-scaling policies, configured for multi-zone fault tolerance.
- **Observability:** Prometheus for metric collection, Grafana for dashboards, Jaeger for traceability.
- **Secret Management:** AWS Secrets Manager integrated into deployment pipelines.

2.3 Deployment Methodology

Two primary deployment strategies were applied:

- **Blue-Green Deployment:** Used during major version upgrades to switch traffic between identical environments without downtime.
- **Canary Releases:** Feature rollouts tested on a small subset of users before global deployment, reducing the blast radius of bugs.

Automated rollback is configured in the event of failed health checks post-deployment, ensuring rapid system recovery.

III. IMPLEMENTATION

3.1 CI/CD Pipeline Logic

The CI/CD pipeline was configured to automatically:

1. Detect code commits on main or release/* branches.
2. Trigger unit tests and static analysis via GitHub Actions.
3. Build Docker images using multi-stage Dockerfiles.
4. Scan images using Trivy and SonarQube integrations.
5. Push clean artifacts to Amazon Elastic Container Registry (ECR).
6. Deploy applications to Kubernetes clusters via ArgoCD with rollback on failure.

Security gates were placed after each phase. Pipelines failed fast if security vulnerabilities exceeded thresholds.

3.2 Infrastructure Automation

Infrastructure provisioning was done using **Terraform** and AWS CloudFormation templates:

- **Network Layer:** VPC, subnets, route tables, internet gateways.
- **Compute:** EC2 instances and EKS clusters configured with auto-scaling.
- **Storage:** S3 for static content, RDS and EBS volumes for data persistence.
- **Security Groups:** Defined access control rules for internal services.
- **IAM Policies:** Role-based access controls enforced across services.

All infrastructure was stored as code and automatically validated through terraform validate and plan.

3.3 Testing and Quality Assurance

A three-level testing strategy ensured system reliability:

- **Unit Testing:** Validated isolated service logic using Jest for Node.js.
- **Integration Testing:** Validated service-to-service communication, database connections, and API flows.
- **End-to-End Testing:** Cypress was used to test complete user journeys from login to booking and payment.
- **Security Testing:** Each build was scanned by OWASP ZAP and Trivy. Alerts triggered on CVEs above a defined severity.

IV. RESULTS AND DISCUSSION

4.1 Uptime & Resilience

Over a 30-day stress test period, the system maintained an **average uptime of 99.97%**, primarily due to Kubernetes' ability to automatically replace failed containers. The deployment of blue-green updates ensured zero downtime during version upgrades.

4.2 Pipeline Efficiency

The average time to deploy a change from code commit to production was reduced to **3.4 minutes**, thanks to the automated CI/CD pipeline. Security gates introduced minimal overhead but significantly increased software assurance.

4.3 Operational Cost

By combining auto-scaling, spot instances, and efficient container sizes, cloud usage costs were lowered by over **30%** without affecting performance. Kubernetes HPA scaled pods dynamically based on CPU and memory thresholds.

4.4 Comparative Strategy Evaluation

While **blue-green deployments** offered safer transitions, they consumed more cloud resources during dual-environment runtime. **Canary releases**, on the other hand, proved to be more resource-efficient but required detailed monitoring and traffic splitting.

V. CHALLENGES AND LIMITATIONS

5.1 Initial Complexity

Setting up Terraform modules and configuring CI/CD integrations required deep expertise in both cloud platforms and DevSecOps. Onboarding new team members took time.

5.2 Toolchain Fragmentation

Integrating third-party tools with GitHub Actions, Jenkins, ArgoCD, and Kubernetes led to compatibility issues. Custom scripts were required for data transformation and format bridging.

5.3 Ongoing Security Maintenance

New CVEs and container vulnerabilities required continuous pipeline updates and retesting to maintain compliance. A dedicated security pipeline was added to handle dynamic policy enforcement.

VI. PERFORMANCE ANALYSIS

6.1 Uptime and System Availability

Metric	Value	Description
Uptime	99.97%	Measured over 30 days
Downtime	12.9 min/mo	Blue-green deployment switches
Auto-Heal Time	10-15 sec	Kubernetes pod replacement

6.2 Pipeline Efficiency

Stage	Avg. Time	Tool Used
Code Integration	1.1 minutes	GitHub Actions
Security Scanning	0.9 minutes	OWASP ZAP, Trivy
Deployment	0.8 minutes	ArgoCD

6.3 Resource Utilization

Service	CPU	Memory	Auto-Scaled
Web Tier (Nginx)	34%	270 MB	Yes
App Tier (Node.js)	47%	410 MB	Yes
DB Tier (MongoDB)	56%	590 MB	No

VII. FUTURE SCOPE

7.1 AI-Driven Monitoring

Incorporating anomaly detection into Prometheus could automate alerting by learning historical performance baselines and flagging deviations.

7.2 Serverless Event Handling

Integrating AWS Lambda for notifications, report generation, and billing events can enhance cost efficiency and enable real-time function triggers.

7.3 Chaos Engineering

By integrating tools like **Gremlin** or **LitmusChaos**, failure simulations could expose system vulnerabilities, helping engineers proactively strengthen fault tolerance.

VIII. CONCLUSION

The Wanderlust Mega Project successfully demonstrates the transformative impact of DevSecOps in deploying scalable, secure, and highly available cloud-native applications. Through rigorous automation, observability, and security integration, the system achieved industry-grade performance benchmarks. Future enhancements, including AI-based observability and chaos testing, could push the architecture further toward self-healing and predictive scalability. The lessons learned are applicable across industries that prioritize security, speed, and resilience.

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