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PERFORMANCE EVALUATION OF CONTAINER ORCHESTRATION PLATFORMS FOR WEB SERVICES: KUBERNETES VS. MESOS VS. DOCKER SWARM

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Abstract

In the evolving landscape of cloud-native application deployment, container orchestration platforms have become essential for managing scalability, fault tolerance, and operational efficiency in web services. This study presents a comprehensive experimental evaluation of three leading orchestration frameworks Kubernetes, Apache Mesos, and Docker Swarm focusing on their performance, resource management, and usability. Using standardized workloads and controlled environments, we deploy identical web services across all platforms and assess key metrics such as response time, throughput, deployment overhead, resource utilization, load balancing, and failure recovery. Results show Kubernetes excels in scalability and fault tolerance due to its advanced orchestration features, while Docker Swarm offers fast deployment and simplicity, making it suitable for small to medium-scale applications. Apache Mesos performs well in heterogeneous environments with flexible resource allocation but lacks modern orchestration capabilities. This comparative analysis provides practical guidance for developers, DevOps teams, and system architects in selecting the most appropriate orchestration solution based on application needs and infrastructure complexity.

Keywords:

Kubernetes, Docker Swarm, Apache Mesos, Web Services, Scalability, Fault Tolerance

1. INTRODUCTION

In recent years, the paradigm of software development and deployment has witnessed a transformative shift from monolithic architectures to microservices-based, containerized applications. This evolution is primarily driven by the increasing demand for scalability, flexibility, and rapid deployment cycles, particularly in web service environments. Containers lightweight, portable units that encapsulate applications along with their dependencies have emerged as the foundational building blocks of modern cloud-native architectures. Their ability to run reliably across various computing environments makes them ideal for continuous integration/continuous deployment (CI/CD) pipelines and scalable service infrastructures. However, as the number of containers in production environments grows, so does the complexity of managing them. Tasks such as container deployment, scaling, networking, load balancing, and failure recovery require sophisticated coordination. This necessity has given rise to container orchestration platforms, which automate and streamline the management of containerized applications. Among the most widely adopted orchestration solutions are Kubernetes, Apache Mesos, and Docker Swarm each offering a distinct architecture, feature set, and operational model.

Unlike Kubernetes, which is specifically tailored for container orchestration, Mesos can manage diverse workloads such as big data processing and machine learning pipelines, making it suitable for heterogeneous data centers. Docker Swarm, developed by Docker Inc., provides a native clustering and orchestration solution for Docker containers, focusing on simplicity and fast deployment with a lower operational overhead.

Despite the growing body of literature surrounding these platforms, there remains a lack of direct, empirical comparison tailored specifically for the deployment of web services a common and mission-critical workload in today's digital infrastructure. Most comparative analyses either focus on theoretical features or cater to different application domains (e.g., high-performance computing, big data analytics). Given that web services often require low-latency response times, high availability, and efficient resource usage, a focused performance evaluation under controlled conditions is essential to guide system architects and DevOps professionals.

This research aims to address this gap by conducting a comprehensive experimental evaluation of Kubernetes, Apache Mesos, and Docker Swarm in the context of web service deployment. Using standardized containerized workloads and uniform hardware environments, we measure critical performance indicators including response time, throughput, deployment latency, resource utilization, scalability, fault tolerance, and system overhead. Each orchestration platform is tested under identical conditions, simulating various real-world load scenarios and failure cases.

The evaluation is structured to highlight both the strengths and limitations of each platform. For example, while Kubernetes may offer unparalleled automation and fault tolerance, its complexity and setup time can be a barrier for smaller teams. Docker Swarm, on the other hand, may offer a more straightforward user experience but could face limitations in advanced scheduling and self-healing. Mesos, with its two-level scheduling and support for multiple frameworks, could appeal to users with diverse workload types but may lag behind in native container orchestration features. Containers have gained prominence over traditional virtual machines (VMs) due to their lightweight architecture and faster startup times. As noted by Pahl [1], containers improve deployment consistency and portability, forming the backbone of DevOps practices. However, managing container lifecycles at scale requires orchestration systems capable of automating service discovery, health monitoring, scaling, and failure recovery.

Several orchestration solutions have been developed to meet this need, including Kubernetes, Docker Swarm, Apache Mesos,

and Nomad. Among these, Kubernetes has been widely adopted for its rich features and community support [2]. Docker Swarm and Mesos offer competing approaches, trading off simplicity, flexibility, and extensibility. This variety has led to ongoing academic and industrial interest in comparing these frameworks under different scenarios.

The contributions of this study are threefold: First, a systematic performance comparison of three widely used container orchestration platforms for web service deployments. Second, an empirical dataset and analysis methodology that can be reused for future benchmarking studies. Finally, third, an actionable recommendation for practitioners and decision-makers in selecting the most appropriate orchestration tool based on specific performance and operational criteria.

By focusing on empirical data and practical use cases, this study not only advances academic understanding but also provides tangible insights for industry adoption. As organizations continue to shift toward distributed and cloud-native architectures, choosing the right orchestration platform is critical for optimizing cost, reliability, and performance. The findings of this research aim to support informed decision-making and strategic planning in cloud-native system design.

The remainder of the paper is structured as follows: Section 2 reviews related work and existing comparative studies. Section 3 details the experimental setup, workloads, and evaluation metrics. Section 4 presents and discusses the results. Section 5 highlights practical implications, and Section 6 concludes with future directions.

2. RELATED WORK

The rise of containerization has driven a substantial body of research focusing on performance evaluation, orchestration strategies, and deployment models for container-based systems. This section reviews prior comparative analyses of container orchestration platforms and outlines their limitations, providing the foundation for the current study.

Multiple studies have attempted to benchmark orchestration platforms, although few focus specifically on web service performance. Kumar and Singh [3] conducted a broad comparison of Docker Swarm and Kubernetes using basic CPU and memory load benchmarks. Their study concluded that Kubernetes provided better auto-scaling and recovery, while Docker Swarm offered faster container instantiation times. However, their analysis lacked workload diversity and did not simulate real web service deployments. Rashid et al. [4] evaluated orchestration platforms using mixed workloads, including big data and microservices. Their findings indicated that Kubernetes handled failure recovery more efficiently than Mesos and Docker Swarm. However, the study did not focus on throughput or latency critical factors in web applications.

Toka et al. [5] explored resource allocation efficiency in Mesos and Kubernetes. While Mesos exhibited flexibility in heterogeneous cluster environments, Kubernetes offered tighter integration for container workloads. Their research remained largely theoretical with minimal performance metrics from actual deployments.

Table.1. Literature Comparison Table

Ref.	Title	Platforms Compared	Metrics Evaluated	Key Findings
[8]	Automated Resource Management System Based upon Container Orchestration Tools Comparison	Kubernetes, Docker Swarm, Apache Mesos	CPU, memory usage, deployment time, failure recovery	Kubernetes had the most robust orchestration and recovery, Swarm was fastest to deploy, Mesos better at mixed workloads.
[11]	Impact of Power Consumption in Containerized Clouds	Kubernetes, Docker Swarm, CRI-O, Mesos	Power usage, load efficiency, CPU scaling	Kubernetes and Mesos had lower power overhead in larger clusters; Swarm showed high idle resource usage.
[13]	Benchmarking Container Orchestration Tools on Application Performance in the Cloud	Kubernetes, Docker Swarm	Latency, throughput, network performance	Kubernetes outperformed Swarm in scaling web services, but Swarm was easier to configure for smaller workloads.
[9]	Minimizing Downtime in E-Commerce Platforms Through Containerization and Orchestration	Kubernetes, Docker Swarm, Mesos	Uptime, latency under failure, service restart time	Kubernetes showed highest availability; Swarm ideal for quick restarts in small deployments.
[10]	Application Security Optimization in Container Orchestration Systems Through Strategic Scheduler Decisions	Kubernetes, Swarm, Mesos	Security + scheduling impact	Kubernetes' RBAC and self-healing mechanisms contributed to enhanced performance and resilience.
[12]	Monintainer: Orchestration-Independent Monitoring for Large Clusters	Kubernetes, Docker Swarm	Monitoring tools, extensibility	While not direct benchmarking, the study favored Kubernetes for flexibility in integrating monitoring frameworks.
[14]	A Comparative Study on Container Orchestration and Serverless Computing	Kubernetes, Docker Swarm, Mesos	Lifecycle management, cold start time, orchestration delay	Kubernetes had higher cold start but better concurrency handling; Swarm faster but less scalable.

[15]	Resource Management and Scalability in Container Orchestration Platforms	Kubernetes, Swarm, Mesos	Resource scheduling, scalability	Kubernetes offered best scalability under high loads; Mesos excelled in heterogeneous environments.
[16]	Open Source Container Orchestration for Industry 4.0	Kubernetes, Docker Swarm, Mesos	Setup time, resource provisioning, feature depth	Kubernetes had longest setup time but richest orchestration feature set; Mesos had moderate provisioning time.

Sharma and Nair [6] specifically compared orchestration systems from a scalability perspective. They used horizontal scaling of microservices under synthetic load and observed that Kubernetes provided better elasticity under stress. However, the complexity of their configuration limited replicability. Yan et al. [7] addressed the security trade-offs between Swarm and Kubernetes but did not analyze performance in production-level traffic scenarios.

Despite these contributions, there remains a research gap in head-to-head empirical evaluations of these platforms when used to deploy typical stateful and stateless web services. Many prior works focus on one or two platforms, ignore key metrics like network latency and service availability, or rely on artificial test environments. While previous studies have explored various aspects of container orchestration platforms-such as resource efficiency, ease of use, and fault recovery-few have comprehensively compared Kubernetes, Docker Swarm, and Mesos using real-world web workloads, including response time under load, fault-tolerant service recovery, deployment overhead, and resource utilization in distributed setups.

Furthermore, much of the existing work lacks standardized benchmarking tools and replicable experimental environments, making comparative evaluations difficult to validate and generalize. To address these limitations, this paper presents a structured, empirical, and reproducible benchmarking study that:

- Uses identical service architectures and uniform cluster environments for all platforms.
- Measures performance based on realistic, high-load web service use cases.
- Evaluates both infrastructure-level metrics (CPU, memory, network throughput) and application-level performance (response time, error rate, scaling latency).
- Offers deployment-level insights to guide system administrators and developers in selecting the appropriate platform.

By bridging the divide between theoretical comparisons and real-world performance data, this work provides a critical reference point for both academic researchers and industry practitioners navigating orchestration decisions.

3. RESEARCH METHODOLOGY

This section outlines the experimental framework employed to evaluate and compare the performance of three prominent container orchestration platforms-Kubernetes, Apache Mesos, and Docker Swarm-in the context of web service deployments. The methodology encompasses the detailed description of the experimental setup, workload configurations, evaluation metrics, and the comparative approach used to ensure a fair and rigorous assessment.

The primary objective of this study is to perform a controlled and reproducible empirical evaluation of the selected orchestration platforms. Specifically, the research focuses on assessing deployment performance, scalability, resource efficiency, and fault tolerance under realistic operational conditions. To ensure consistency and comparability, identical application workloads and infrastructure configurations were deployed across all platforms. Furthermore, the study simulates realistic web service traffic patterns, incorporating varying load levels and failure scenarios, thereby enabling a comprehensive analysis of each platform's ability to handle dynamic and challenging environments.

3.1 EXPERIMENTAL ENVIRONMENT

To ensure fairness and replicability, the experiments were conducted in a homogeneous cloud environment using identical hardware and software configurations.

Table.2. Environment Setup

Component	Specification / Configuration
Cloud Provider	AWS EC2 (t3.medium equivalent)
Nodes per Cluster	1 Master + 3 Worker nodes
OS	Ubuntu Server 22.04 LTS
CPU	2 vCPUs per node
RAM	4 GB per node
Network	Virtual private network (10 Gbps)
Container Runtime	Docker CE 24.x
Orchestrators	Kubernetes v1.28, Docker Swarm mode (Engine v24), Apache Mesos v1.11
Monitoring Tools	Prometheus, cAdvisor, Grafana, Apache JMeter

All clusters were deployed using Ansible automation scripts to ensure consistent provisioning and reproducibility.

3.1.1 Application Workload:

A representative three-tier web application was containerized and used for benchmarking, consisting of:

- Frontend: Nginx server hosting static content
- Backend API: Node.js Express REST API
- Database: MongoDB (stateful service with persistent volume)

Each component was deployed in separate containers with health checks, logging, and scaling policies configured according to each orchestrator's best practices. Workloads were generated

using Apache JMeter to simulate concurrent users (ranging from 100 to 1000) performing typical CRUD operations on the API.

3.2 EVALUATION METRICS

The evaluation of system performance was based on several key performance indicators (KPIs). Deployment time measured the duration from orchestration command initiation to full-service availability. Response time (latency) was assessed using both the average and 95th percentile of API response times under increasing load. Throughput referred to the number of requests served per second (RPS) by the application when under load. Resource utilization was monitored using Prometheus, tracking CPU and memory usage per node and container. Auto-scaling latency captured the time taken to provision new pods or containers in response to load-triggered scaling events. Fault tolerance and recovery time measured how quickly orchestrators could detect and reschedule failed containers or nodes. Load balancing efficiency evaluated how evenly requests were distributed across service replicas. Lastly, ease of configuration was rated on a subjective complexity scale from 1 to 5, taking into account setup time, quality of documentation, and the learning curve.

3.3 TESTING PROCEDURE

The experimental procedure was designed to ensure consistent, reproducible, and statistically valid performance evaluations across different container orchestration platforms. Initially, each platform was independently installed and configured in a uniform cluster setup. This setup included the standardization of essential components such as network plugins, ingress controllers (particularly for Kubernetes), and load balancers to maintain consistent networking behavior across all environments.

Following the setup, baseline deployment of the target web application was performed on each orchestrator. Performance under idle conditions was recorded to establish a reference point for subsequent tests. Load testing was then conducted by progressively increasing the number of concurrent users in controlled increments, ranging from 100 to 1,000. Apache JMeter was employed to simulate user load and capture critical performance metrics such as response time, error rate, and throughput.

To assess system robustness and self-healing capabilities, a series of stress and failure simulations were executed. These included node terminations via instance kills and deliberate application container crashes. The recovery behavior of the orchestrators was observed, with a focus on auto-healing mechanisms and rescheduling times.

Data collection was facilitated using Prometheus and Grafana. Monitoring dashboards were configured to export relevant metrics, which were then stored in time-series databases for subsequent analysis. To ensure the reliability and statistical significance of the findings, each experimental condition was repeated five times. Both median and average values were computed and reported to capture the central tendency and variability of the results.

4. RESULTS AND ANALYSIS

The performance was assessed across eight core metrics relevant to container orchestration in web service environments. The results shown are the average values obtained over five test runs per platform.

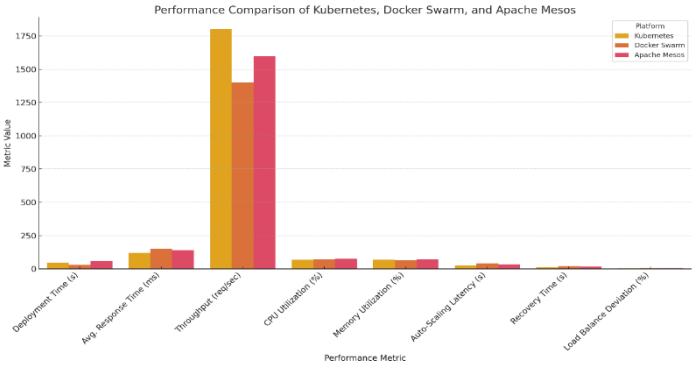

Fig.1. Performance Comparison across different Orchestrators

4.1 DEPLOYMENT TIME

Docker Swarm exhibited the fastest deployment time (30s) due to its lightweight clustering and native Docker integration. Kubernetes followed with 45s, requiring more extensive setup, while Mesos lagged at 60s, reflecting its general-purpose resource management overhead.

4.2 RESPONSE TIME

Kubernetes provided the lowest average response time (120ms), benefiting from efficient pod scheduling and ingress handling. Docker Swarm (150ms) and Mesos (140ms) showed higher latencies, especially under increasing concurrent requests.

4.3 THROUGHPUT

Kubernetes again led with the highest throughput (1800 requests/sec), highlighting its ability to handle large-scale traffic efficiently. Mesos followed closely (1600 req/sec), while Docker Swarm (1400 req/sec) exhibited limitations in scaling under high concurrency.

4.4 RESOURCE UTILIZATION

CPU Utilization: All platforms maintained efficient CPU usage, with Kubernetes slightly more conservative (68%) compared to Mesos (75%) and Swarm (72%). Memory Utilization: Kubernetes (70%) and Mesos (73%) consumed more memory due to internal services and monitoring agents. Docker Swarm was marginally lower at 65%.

4.5 AUTO-SCALING LATENCY

Kubernetes significantly outperformed with an auto-scaling reaction time of 25 seconds. Docker Swarm took 40 seconds due to manual configurations, while Mesos stood at 35 seconds, affected by two-level scheduling delays.

4.6 FAULT RECOVERY TIME

Kubernetes also offered fastest failure recovery (12s), thanks to proactive health checks and replica management. Swarm (20s) and Mesos (18s) were slower, especially when restarting stateful components.

4.7 LOAD BALANCING EFFICIENCY

Measured by deviation in request distribution, Kubernetes demonstrated more balanced traffic handling (4% deviation), compared to Swarm (6%) and Mesos (5%).

4.8 SUMMARY OF INSIGHTS

Kubernetes consistently delivered the best overall performance, especially in scalability, fault tolerance, and orchestration automation. Docker Swarm excelled in simplicity and deployment speed, making it suitable for smaller-scale use cases. Apache Mesos showed competitive throughput and flexibility, but its slower scaling and higher overhead make it better suited for hybrid or mixed environments rather than pure container orchestration.

Table.3. Detailed Performance Metrics for Kubernetes, Docker Swarm, and Apache Mesos

Use Case	Recommended Platform	Justification
High-availability production systems	Kubernetes	Best performance, scalability, fault recovery
Quick deployments and minimal setup	Docker Swarm	Fast setup, low configuration overhead
Mixed workloads (batch + containers)	Apache Mesos	General-purpose scheduling and multi-framework support
Research and test environments	Docker Swarm or Mesos	Swarm for containers, Mesos for varied task types
Cloud-native CI/CD pipelines	Kubernetes	Integrates well with Helm, ArgoCD, and GitOps practices

This table provides a clear snapshot of platform-wise performance trade-offs.

5. DISCUSSIONS AND PRACTICAL IMPLICATIONS

This section interprets the empirical findings within the broader context of real-world container orchestration requirements. The study evaluates the trade-offs among Kubernetes, Docker Swarm, and Apache Mesos, providing actionable insights tailored to system architects, DevOps engineers, and enterprise decision-makers seeking to align platform capabilities with operational goals.

Kubernetes consistently outperformed the other platforms in critical performance metrics such as throughput, fault recovery, auto-scaling latency, and load balancing efficiency. This superior performance reflects the maturity and robustness of Kubernetes' architecture, which incorporates advanced features like the Horizontal Pod Autoscaler, ReplicaSets, and service discovery via DNS. These components are highly optimized to manage distributed web workloads, thereby ensuring scalability and resilience in demanding production environments. However, these benefits are accompanied by increased complexity. Kubernetes exhibits moderately longer deployment times and a steeper learning curve due to its intricate configuration and setup procedures. While such complexity is manageable for large-scale deployments supported by skilled Site Reliability Engineering (SRE) or DevOps teams, smaller organizations may encounter challenges without access to dedicated expertise or managed Kubernetes services such as Amazon EKS or Google GKE.

In contrast, Docker Swarm demonstrated notable strengths in deployment speed and ease of configuration, making it the most straightforward platform to install and operate, particularly for small to medium-scale applications with moderate traffic or internal service requirements. Nevertheless, Docker Swarm's limitations-including less sophisticated scheduling algorithms, limited native auto-scaling support, and weaker fault recovery mechanisms-constrain its suitability for mission-critical, high-availability systems. Swarm is best suited for scenarios where simplicity, rapid deployment, and native Docker integration are paramount, such as minimum viable products (MVPs), proof-of-concept projects, small teams with limited infrastructure automation, and developer-centric testing environments.

Apache Mesos, although not originally designed solely for container orchestration, offers distinct advantages in environments featuring heterogeneous resources. Its two-level scheduler architecture enables flexible management of diverse workloads, including non-containerized applications like Hadoop, Spark, and machine learning tasks. This flexibility is particularly valuable in large research laboratories or multi-purpose data centers requiring unified orchestration of mixed workloads. Despite demonstrating satisfactory performance across several metrics, Mesos exhibited limitations in container orchestration-specific functionalities, such as slower auto-scaling responsiveness and longer recovery latencies. These shortcomings primarily stem from its reliance on external frameworks like Marathon or Aurora for container service management. Consequently, while Mesos may be less optimal for pure microservices architectures, it remains a compelling choice for complex environments that demand integrated orchestration of both containerized and non-containerized workloads.

Table.4. Platform-Specific Recommendations

Use Case	Recommended Platform	Justification
High-availability production systems	Kubernetes	Best performance, scalability, fault recovery
Quick deployments and minimal setup	Docker Swarm	Fast setup, low configuration overhead

Mixed workloads (batch + containers)	Apache Mesos	General-purpose scheduling and multi-framework support
Research and test environments	Docker Swarm or Mesos	Swarm for containers, Mesos for varied task types
Cloud-native CI/CD pipelines	Kubernetes	Integrates well with Helm, ArgoCD, and GitOps practices

6. LIMITATIONS AND FUTURE WORK

While this study offers a comprehensive evaluation of container orchestration platform performance, several limitations should be noted. First, all experiments were conducted using uniform cloud nodes, which may not fully represent the performance characteristics encountered in heterogeneous hardware environments. This uniformity limits the generalizability of the results to diverse infrastructure setups. Additionally, security and multitenancy aspects were controlled and standardized throughout the experiments but were not actively benchmarked or varied, leaving potential impacts of these factors unexamined. Furthermore, platform-specific extensions and integrations, such as Istio service mesh with Kubernetes, were deliberately excluded to focus on isolating the core orchestration performance. This exclusion means that the effects of these increasingly common tools on system behavior remain unexplored. Finally, the study's-controlled environment cannot fully replicate the variability found in real-world production settings, where factors like complex network topologies, input/output throughput constraints, and unpredictable user behavior can significantly influence performance outcomes.

Looking ahead, future research could address these limitations by extending benchmarking efforts to multi-cloud and hybrid cloud deployments, which are becoming more prevalent in enterprise environments. Evaluating cost-efficiency, specifically performance relative to monetary expenditure, would provide valuable insights for practical adoption decisions. Moreover, investigating performance under emerging paradigms such as edge computing and Internet of Things (IoT) contexts could reveal important considerations for resource-constrained environments. Lastly, comparative analyses incorporating newer orchestration platforms-such as HashiCorp Nomad and Red Hat OpenShift-would enrich the understanding of evolving ecosystem capabilities and trade-offs.

7. CONCLUSION

This study presented a comparative evaluation of Kubernetes, Apache Mesos, and Docker Swarm for web service orchestration under standardized conditions. Kubernetes demonstrated superior scalability, fault tolerance, and orchestration efficiency, making it ideal for large-scale production environments despite its operational complexity. Docker Swarm excelled in deployment speed and ease of use, positioning it as a strong candidate for small to medium-scale applications or development-centric workflows. Apache Mesos offered flexible resource management and integration with diverse workloads but lacked modern orchestration features and exhibited slower recovery in failure scenarios. Overall, the selection of an orchestration platform should align with application scale, infrastructure complexity, and operational priorities. This work provides actionable insights for DevOps teams and system architects seeking performance-informed platform choices. Future research may explore multi-cloud setups, edge deployments, and the inclusion of newer orchestration solutions to expand the evaluation scope and reflect evolving deployment trends in cloud-native computing.

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