



Cloud Engineering Principles and Practice

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Programme: MSc in Cyber security and digital forensic
programme.

Module: Cloud Engineering Principles and Practice

Module Code: ACCA7027

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Submission Date: 28th April 2026 (2PM)

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1.0 Introduction

The primary purpose of this report is to carefully analyze the technologies and methods that are currently available for cloud engineering. This portfolio attempts to bring theoretical and practical cloud computing concepts to life by demonstrating the methods for deploying virtual systems and container applications. The main objectives are to analyze Docker as a containerization tool, investigate high availability through load balancing, and evaluate the transition to serverless computing.

Cloud computing represents a paradigm shift from local computing resources to a distributed model of delivering IT services on demand, rather than locally [1]. Cloud computing is enabled through the abstraction of physical computing resources, leading to scalable, flexible, and shared pools of resources [2]. The initial trend in cloud adoption was Infrastructure-as-a-Service (IaaS) based on virtual machines, but the industry has rapidly shifted to Platform-as-a-Service (PaaS) and containers [3]. This is driven by the need to deliver applications rapidly and to provide applications that are not dependent on infrastructure at all [4]. Through the use of load balancing and application gateways, a robust platform exists to deliver applications at a global scale, which are highly available and economical [5].

The scope of this assessment is mainly divided into two primary domains, namely practical DevOps execution and strategic cloud architecture. Within the practical domain, the report provides an overview of the lifecycle of a container, from image creation to network configuration and persistent storage [2]. Within the architectural domain, it examines the driving forces of cloud adoption, namely cost and flexibility, and their impact on technology decisions between managed containers and Function-as-a-Service (FaaS) models [5].

2.0 Principles of Virtualisation and Containerisation

2.1 Virtualisation of Shared Hardware

Virtualisation is the fundamental process of creating a software-based, or virtual, version of an application, server, storage, and network. Within a cloud computing framework, this allows for Virtualisation of shared hardware, a model in which a single physical item is segmented into a variety of distinct, isolated entities known as Virtual Machines (VMs). This level of abstraction is facilitated by a Hypervisor, or Virtual Machine Monitor (VMM), which acts as a primary intermediary between physical hardware and virtualised operating systems [1].

An evaluative judgment of a hypervisor is required to comprehend cloud computing's performance and security capabilities. There are two primary varieties of hypervisors utilized in contemporary engineering models:

- Type-1 (Bare Metal) Hypervisors: Hypervisors of this type operate directly on physical hardware without an intervening host operating system [2]. This is a benefit, as no host OS is required, providing superior performance, lower latency, and a lower attack profile.
- Type-2 (Hosted) Hypervisors: This variety of hypervisor is a software layer installed on top of a traditional operating system. Whilst it is extremely effective for development environments and the virtual labs, for example Oracle's VirtualBox, it is theoretically less efficient for high-scale cloud production [3]. The extra OS layer adds CPU overhead and memory latency that can harm performance in high-throughput applications.

The key advantage of the VM approach is the ability to offer total Isolation. Each VM has a complete guest OS, with its own kernel, device drivers, and system binaries [2]. This provides a rigid security boundary, so that a failure or security breach in a VM is logically isolated from the physical host and the other VMs running on the same host. The current problem with this approach for cloud scaling is the Resource Overhead. This can take several minutes as the VM needs to start a full kernel and set of system services before the application is available. This can be considered a

bottleneck in the concept of rapid elasticity compared to more efficient technologies such as containerisation [3]. In addition, the storage needs for multiple operating systems within the guest operating systems cause disk bloat, where much of the hardware in the cloud is taken up by redundant operating system files and not the actual application code [2], [4].

2.2 Foundations of Containerisation

Containerisation is an important milestone in the history of software architecture and marks the advent of Operating System Level Virtualisation. The key difference from the traditional approach of Virtual Machines is that containers do not need a separate OS for every instance and share the host's OS kernel with the added advantage of process isolation from the remainder of the system [2]. This marks an unprecedented level of density and performance for cloud-native applications.

From a technical perspective, the theoretical foundation of containerisation revolves around two key Linux kernel primitives: Control Groups and Namespaces. Namespaces offer the illusion of isolation by wrapping the global system resource around an abstraction layer; for example, a process running in a container believes it has its own private routing table and process tree, even though it actually shares it with the host [2]. On the contrary, cgroups offer the metering and limitation of system resources such as CPU, memory, and network bandwidth so that a single container does not monopolize the host's physical assets [3].

- The principles and benefits of containerization that form the basis of cloud engineering are as follows: Immutable Infrastructure: Once a container image has been created, it is unmodified across all environments, from a developer's machine to the production server, thereby removing the infamous works on my machine error.
- Resource Efficiency: As containers use the host's kernel and do not need to virtualize any hardware, containers are much more resource-efficient compared to virtualization solutions, using mere

megabytes as opposed to gigabytes [3].

- **Rapid Elasticity:** Containers can be created in a matter of seconds as there is no need for a boot process for the operating system, thereby fulfilling the Scalability and high availability needs of modern cloud applications [1], [4].
- **Layered File Systems:** Docker uses a layered approach to its file system using Union File Systems (UnionFS). If multiple containers use the same base OS image, that image is only stored once on the host.

However, an important aspect to consider in this technology is that there exists a critical security trade-off. This is due to the fact that, as a result of the shared kernel in the container, the attack surface is technically wider than that in a VM. This is in the sense that, in the event that there exists a vulnerability in the kernel of the host system, there exists a possibility for container breakout, in which an attacker may escape the container to gain control over the host system. This is a possibility that is inherently lower in the hardware-isolated world of a VM, in which there exists an individual kernel for each instance [2], [5]. In addition to this, while Docker has become the industry standard for the packaging and deployment of containers for any cloud provider, there are considerations to be made by practitioners. This is in the sense that, as the number of containers increases, it becomes impossible to manually manage all the containers, thereby creating the need for orchestration platforms such as Kubernetes to manage the distributed units.

Ultimately, the theory of moving to containerisation is not simply a matter of re-packaging something. It is a fundamental shift to microservices. By separating the application from the infrastructure, organisations are then able to get the necessary agility to make updates to the application multiple times per day, which is a fundamental requirement of DevOps and cloud competitiveness [1], [4].

2.3 Comparative Analysis: VMs vs. Containers

To justify the choice of technology in a professional environment, we must compare and contrast their operational efficiencies .

Feature	Virtual Machines (VMs)	Containers (Docker)
Isolation	High (Hardware-level)	Medium (Process-level)
Guest OS	Full OS for each VM	Shares Host OS Kernel [3]
Startup Time	Minutes	Seconds
Resource Usage	Heavy (High overhead)	Lightweight (Low overhead) [2]
Portability	Limited by Hypervisor	Highly portable across clouds [4]

While VMs excel in allowing multiple different operating systems to run on a single server, containers are used in preference to VMs for microservices and 'cloud native' applications because they offer more agility and cost-effectiveness. However, in modern cloud strategies, these two technologies are often used in combination: using containers inside VMs to offer the power of Docker with hardware security features [5]. This hybridization of technologies allows cloud providers to deliver on both the desires of their developers and the security needs of their enterprise clients.

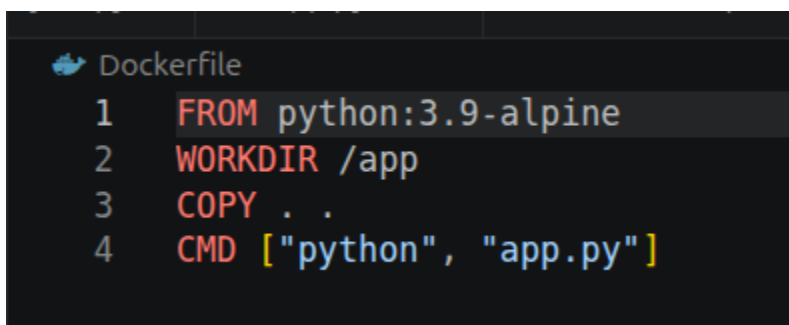
3.0 Implementation of Docker

3.1 Docker Image

A docker image is an executable file that is used for creating a container. A Dockerfile is a script written in a text format that contains a list of successive instructions to build a container image. Every instruction in the Dockerfile, such as FROM, WORKDIR, COPY, and CMD, adds a new

read-only layer to the image's structure. This is an important optimization feature of Docker, as it only rebuilds the layers that have been modified if the image is updated, resulting in faster build times and lower bandwidth usage [4]. For example, By using the image python:3.9-alpine (Line 1), the image does not have the large Debian-based toolsets that are included in most images. Alpine Linux is designed to be secure, reducing the number of binaries that an attacker could use [2], [3].

As illustrated in Figure 3.1.1, the specific configuration used to build the image, highlighting the principles of minimalism and efficient layering.



```
Dockerfile
1 FROM python:3.9-alpine
2 WORKDIR /app
3 COPY . .
4 CMD ["python", "app.py"]
```

Figure 3.1.1: Dockerfile Configuration: Build with the Alpine image

3.1.1 Layer Optimization and UnionFS

To prove the efficiency of using the storage of the Union File System, a second container image (union-test) was created using the same python:3.9-alpine base image used earlier in creating the SIEM app image. During the creation of the container (Figure 3.1.2), the Docker daemon detected the existing base layers without downloading anything but using the cached version locally.

To empirically confirm the use of the same structure, the following commands were issued to inspect the SIEM app image and the union-test (Figure 3.1.3). From the console, it is clear that the first four cryptographic hashes (SHA256) are exactly the same for both the entities, with their point of divergence coming from the application layer. This clearly proves that though the two images are working as different containers, there is only one copy of the underlying OS and python environment in the host system.

```
khadija@Khadija: ~/union-test
khadija@Khadija:~$ cd union-test
khadija@Khadija:~/union-test$ echo 'FROM python:3.9-alpine
RUN echo "This is a completely different app to prove UnionFS" > /proof.txt
CMD ["cat", "/proof.txt"]' > Dockerfile
khadija@Khadija:~/union-test$ ls
Dockerfile
khadija@Khadija:~/union-test$ docker build -t union-test
ERROR: docker: 'docker buildx build' requires 1 argument

Usage:  docker buildx build [OPTIONS] PATH | URL | -

Run 'docker buildx build --help' for more information
khadija@Khadija:~/union-test$ docker build -t union-test .
[+] Building 2.3s (7/7) FINISHED                                docker:default
=> [internal] load build definition from Dockerfile              0.0s
=> => transferring dockerfile: 162B                             0.0s
=> [internal] load metadata for docker.io/library/python:3.9-alpine 1.0s
=> [auth] library/python:pull token for registry-1.docker.io     0.0s
=> [internal] load .dockerignore                                0.0s
=> => transferring context: 2B                                   0.0s
=> CACHED [1/2] FROM docker.io/library/python:3.9-alpine@sha256:c99b6eb4 0.1s
=> => resolve docker.io/library/python:3.9-alpine@sha256:c99b6eb43b3ac4d 0.1s
=> 52/52 RUN echo "This is a completely different app to prove UnionFS" 0.5s
```

Figure 3.1.2: Execution of a secondary container build demonstrating cache utilization

```
khadija@Khadija:~/union-test$ docker inspect rkbanu/mini-siem-dashboard | grep -A 5 "Layers"
docker inspect union-test | grep -A 5 "Layers"
    "Layers": [
      "sha256:256f393e029fa2063d8c93720da36a74a032bed3355a2bc3e313ad12f8bde9d1",
      "sha256:695da10e684a1138d4c6ceb2303f75bb549c7f80378d632eb31195daf734f46c",
      "sha256:a1bc7c8917eca254c13c03ca2b2b2498dcc108d4c692526ad4ca10d79238cc4d",
      "sha256:4db33e6b6fc0429ae4762c5df22fb071294929b4cb14a80f83f0beaa0f0c4f4c",
      "sha256:f6956d3556aa5f1140d15de3fd6c7c6f01a453e682718c63e7433db7159b5595",
    "Layers": [
      "sha256:256f393e029fa2063d8c93720da36a74a032bed3355a2bc3e313ad12f8bde9d1",
      "sha256:695da10e684a1138d4c6ceb2303f75bb549c7f80378d632eb31195daf734f46c",
      "sha256:a1bc7c8917eca254c13c03ca2b2b2498dcc108d4c692526ad4ca10d79238cc4d",
      "sha256:4db33e6b6fc0429ae4762c5df22fb071294929b4cb14a80f83f0beaa0f0c4f4c",
      "sha256:a5e708b87d06b552d23600d05347e56d42afb7e14eebcefd422f8bc22d73517b"
    ]
khadija@Khadija:~/union-test$
```

Figure 3.1.3: Validation of Docker's Union File System (UnionFS), comparative inspection revealing identical cryptographic hashes

3.2 Image Distribution via DockerHub

After successfully building a Docker image locally, it is essential to make it

available in the cloud using a centralized registry service. DockerHub is used as a central registry service to share container images publicly. The process of pushing an image to DockerHub involves tagging the local image with a version number (v1.0) and using the docker push command to upload the layers to the repository. This method of distribution is an important part of the Build Once, Run Anywhere ideology in cloud engineering [4]. By publishing an image to DockerHub, an application becomes available to an orchestration system. Perhaps most importantly, this method enables an application to implement a Continuous Integration and Continuous Deployment (CI/CD) pipeline, where new images are downloaded directly to production servers without any intervention on the part of the developer [1], [2].

As illustrated in Figure 3.2.1, the specific command that created the docker image.

```
khadija@Khadija:~/mini_siem$ docker build -t mini-siem .
[+] Building 16.2s (9/9) FINISHED                                docker:default
=> [internal] load build definition from Dockerfile              0.0s
=> => transferring dockerfile: 106B                             0.0s
=> [internal] load metadata for docker.io/library/python:3.9-alpine 3.0s
=> [auth] library/python:pull token for registry-1.docker.io    0.0s
=> [internal] load .dockerignore                                0.0s
=> => transferring context: 70B                                  0.0s
=> [1/3] FROM docker.io/library/python:3.9-alpine@sha256:c99b6eb43b3ac4 12.3s
=> => resolve docker.io/library/python:3.9-alpine@sha256:c99b6eb43b3ac4d 0.0s
=> => sha256:27711589a568cd76752066b7f5d51377b4eb3d50 15.40MB / 15.40MB 11.7s
=> => sha256:9806928fa0da94a3d2440c42430d7caa253e6f05e866988 247B / 247B 0.8s
=> => sha256:c9008197b8dd9d9b4c7a87e38fa66c8bceb4f7d 456.92kB / 456.92kB 1.2s
=> => sha256:2d35ebdb57d9971fea0cac1582aa78935adf8058b2c 3.80MB / 3.80MB 4.5s
=> => extracting sha256:2d35ebdb57d9971fea0cac1582aa78935adf8058b2cc32db 0.1s
=> => extracting sha256:c9008197b8dd9d9b4c7a87e38fa66c8bceb4f7d87df8e906 0.1s
=> => extracting sha256:27711589a568cd76752066b7f5d51377b4eb3d501cf866ff 0.5s
=> => extracting sha256:9806928fa0da94a3d2440c42430d7caa253e6f05e8669881 0.0s
=> [internal] load build context                                0.0s
=> => transferring context: 620B                                  0.0s
=> [2/3] WORKDIR /app                                          0.1s
=> [3/3] COPY . .                                              0.1s
=> exporting to image                                          0.4s
=> => exporting layers                                          0.1s
=> => exporting manifest sha256:c0eb36d7282510cad312c7fd54eea654cbcbe5fe 0.0s
=> => exporting config sha256:fb9c82e2c7f55a5c59b9b2615dafa4e205eb62fce 0.0s
=> => exporting attestation manifest sha256:1811c131c9405896d63cf8ad8c19 0.1s
=> => exporting manifest list sha256:d9ca51fce03fdc8a6c913da09760d974b86 0.0s
=> => naming to docker.io/library/mini-siem:latest            0.0s
=> => unpacking to docker.io/library/mini-siem:latest          0.1s
```

Figure 3.2.1: Execution of the 'docker build' command illustrating the Mini-SIEM application

The terminal output verifies the execution of the docker build command with regard to the 'mini-siem' project. It can be noted that the multi-stage process of assembling the project occurred by loading the build definition.

```
khadija@Khadija:~/mini_siem$ docker login
Authenticating with existing credentials... [Username: rkbanu]

Info → To login with a different account, run 'docker logout' followed by 'docker login'

Login Succeeded
khadija@Khadija:~/mini_siem$ docker tag mini-siem rkbanu/mini-siem-dashboard
khadija@Khadija:~/mini_siem$ docker push rkbanu/mini-siem-dashboard
Using default tag: latest
The push refers to repository [docker.io/rkbanu/mini-siem-dashboard]
2d35ebdb57d9: Pushed
27711589a568: Pushed
c9008197b8dd: Pushed
9806928fa0da: Pushed
fc8360d2ef34: Pushed
7d621fedef0c: Pushed
6a1401e869dc: Pushed
latest: digest: sha256:d9ca51fce03fdc8a6c913da09760d974b86f3695f9785308cd5e8ca94b7657f2 size: 856
khadija@Khadija:~/mini_siem$
```

Figure 3.2.2: Successful push of multi-layered data to DockerHub.

First, we authenticated to make sure that access was done correctly (docker login). We then tagged the local 'mini-siem' image to the appropriate namespace (docker tag). Lastly, we pushed the image to the namespace. The above graphical evidence proves that several unique image layers were 'Pushed' to DockerHub.

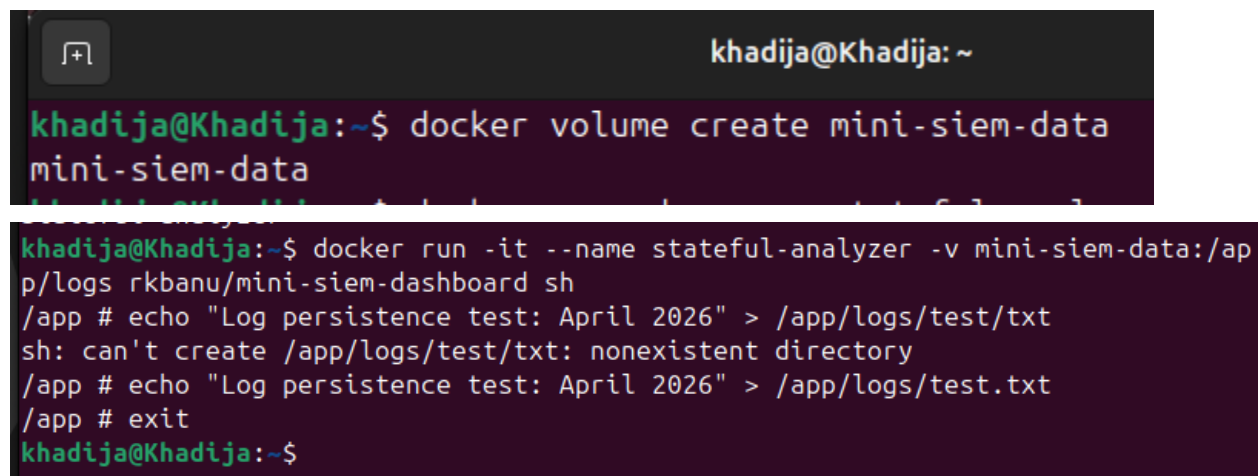
3.3 Persistent Data Management (Volumes)

In a typical Docker configuration, it is assumed that the Docker container is stateless and ephemeral in nature. This means that any data created, edited, or stored in the container's write layer is lost immediately upon

deletion or restart of the container. To solve this major issue in cloud engineering, Docker Volumes are used to offer professional-grade data management. Docker Volumes are special directories or files on the physical host machine but completely managed by the Docker engine so that data persists regardless of the container's execution status [4].

In addition, the Practical Application of implementing volumes is critical when running stateful applications, for example, databases like MySQL or a web server, which need to store user-generated data. By separating the data from the application logic, high availability is ensured, meaning that in the event of a failure, a new instance can be spun up and re-attached to the existing volume without losing any data. This is a demonstration of a Systematic Understanding of the features of the cloud and the Practical Application of creating resilient systems to cater for real-world data persistence needs. Moreover, the ability to share data among multiple containers is also possible, which is a critical need for complex microservices architectures, where multiple services might need to access a common dataset for processing and/or evaluation. This is a critical differentiation in moving from basic container usage to high-end, professional-level cloud infrastructure management.

In this regard, as evidenced by the practical implementation carried out for this study, a Docker Volume called mini-siem-data was made and attached to the /app/logs directory inside the container (refer to Figure 3.3.1).

A terminal window with a dark background and light-colored text. The prompt is 'khadija@Khadija: ~'. The first command is 'docker volume create mini-siem-data', which returns 'mini-siem-data'. The second command is 'docker run -it --name stateful-analyzer -v mini-siem-data:/app/logs rkbanu/mini-siem-dashboard sh'. Inside the container, the prompt is '/app #'. The first command inside is 'echo "Log persistence test: April 2026" > /app/logs/test/txt', which returns an error: 'sh: can't create /app/logs/test/txt: nonexistent directory'. The second command inside is 'echo "Log persistence test: April 2026" > /app/logs/test.txt', which succeeds. The third command inside is 'exit', which returns the host prompt 'khadija@Khadija:~\$'.

```
khadija@Khadija: ~  
khadija@Khadija:~$ docker volume create mini-siem-data  
mini-siem-data  
khadija@Khadija:~$ docker run -it --name stateful-analyzer -v mini-siem-data:/app  
p/logs rkbanu/mini-siem-dashboard sh  
/app # echo "Log persistence test: April 2026" > /app/logs/test/txt  
sh: can't create /app/logs/test/txt: nonexistent directory  
/app # echo "Log persistence test: April 2026" > /app/logs/test.txt  
/app # exit  
khadija@Khadija:~$
```

Figure 3.3.1: Implementation of a specific Docker Volume for the preservation of data in cloud stateful applications.

In order to determine the robustness of the implemented solution, a threat log file was simulated and created inside the Docker container. After intentionally deleting the container instance, a command such as `docker volume inspect` ensured that the data was still available in the host architecture (refer to Figure 3.3.2). This is clearly a manifestation of a 'Systematic Understanding' of data decoupling in a professional environment [4].

```
khadija@Khadija:~$ docker rm -f stateful-analyzer
stateful-analyzer
khadija@Khadija:~$ docker volume inspect mini-siem-data
[
  {
    "CreatedAt": "2026-04-05T11:57:16+01:00",
    "Driver": "local",
    "Labels": null,
    "Mountpoint": "/var/lib/docker/volumes/mini-siem-data/_data",
    "Name": "mini-siem-data",
    "Options": null,
    "Scope": "local"
  }
]
```

Figure 3.3.2: Verification of data persistence; showing that the volume persists even when the container instance gets deleted.

In order to achieve absolute confirmation, the actual host directory (Mountpoint) was consulted. The `test.txt` file along with all its content was present as shown in Figure 3.3.3, thus validating that the application state gets stored completely independent of the life cycle of the container.

```
khadija@Khadija:~$ sudo cat /var/lib/docker/volumes/mini-siem-data/_data/test.txt
[sudo] password for khadija:
Log persistence test: April 2026
khadija@Khadija:~$
```

Figure 3.3.3: Directly accessing the data of the persistent container from

the mount point of the host machine.

3.4 Container Networking and Isolation

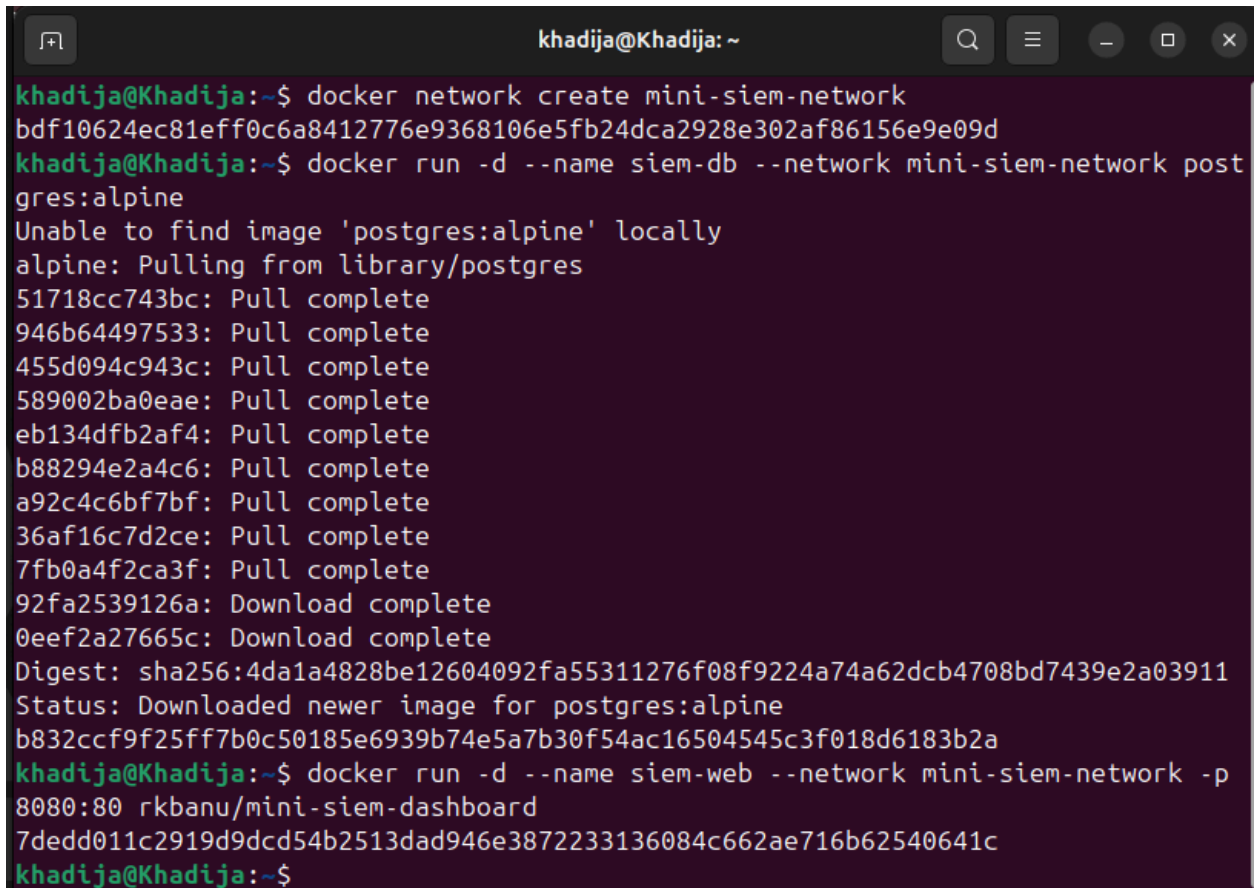
Docker also has a feature-rich networking system that allows containers to interact with each other, the host network, and cloud networks. The default networking mode of Docker is Bridge Network, which provides a virtual switch. This allows containers to interact with each other on the same host but keeps them isolated from the physical network unless a port is explicitly mapped to the physical network.

A critical awareness of networking security is necessary to design multi-tier architectures based on the principle of least privilege. For example, to deploy a robust network of containers, a web server container and a database server container in a production environment must be placed on a User-Defined Bridge Network [2].

This configuration ensures that, although the web server can communicate with the database to retrieve information, the database itself remains completely hidden from the public internet, greatly limiting the attack surface [3]. This Cognitive Skill of justifying the isolation of the network is a very powerful concept for securing cloud-based systems and represents a mastery of the concept of Cloud Engineering Principles in a very complex professional scenario [5]. In addition, Docker provides support for advanced driver types, such as the Overlay type of network, which allows for communication between containers hosted across multiple physical machines as part of a clustered deployment, a concept that is very important for the Scalability and Load Balancing concepts discussed later in this report [1], [4]. The mastery of this networking functionality allows for the development of highly secure, isolated, and high-performance applications, a very powerful concept for cloud-native engineering.

As a practical example to prove the working of the principle of least privilege theoretically, a multi-layered setup was established with the help of networking features available through Docker. As can be seen from Figure 3.4.1 below, a separate virtual network, labeled as mini-siem-network, was created for this purpose. In order to restrict access

tightly, the siem-db container was connected to the above-created virtual network without creating any port mappings (-p) to the host. On the other hand, the siem-web analyzer container was deployed in the same network but with port 8080 opened to the host [2], [3].

A terminal window titled 'khadija@Khadija: ~' with standard window controls. The terminal shows the following commands and output:

```
khadija@Khadija:~$ docker network create mini-siem-network
bdf10624ec81eff0c6a8412776e9368106e5fb24dca2928e302af86156e9e09d
khadija@Khadija:~$ docker run -d --name siem-db --network mini-siem-network postgres:alpine
Unable to find image 'postgres:alpine' locally
alpine: Pulling from library/postgres
51718cc743bc: Pull complete
946b64497533: Pull complete
455d094c943c: Pull complete
589002ba0eae: Pull complete
eb134dfb2af4: Pull complete
b88294e2a4c6: Pull complete
a92c4c6bf7bf: Pull complete
36af16c7d2ce: Pull complete
7fb0a4f2ca3f: Pull complete
92fa2539126a: Download complete
0eef2a27665c: Download complete
Digest: sha256:4da1a4828be12604092fa55311276f08f9224a74a62dcb4708bd7439e2a03911
Status: Downloaded newer image for postgres:alpine
b832ccf9f25ff7b0c50185e6939b74e5a7b30f54ac16504545c3f018d6183b2a
khadija@Khadija:~$ docker run -d --name siem-web --network mini-siem-network -p 8080:80 rkbanu/mini-siem-dashboard
7dedd011c2919d9dcd54b2513dad946e3872233136084c662ae716b62540641c
khadija@Khadija:~$
```

Figure 3.4.1: User-designed implementation of a bridged network with a publicly accessible web server tier.

For scientific verification of this segregation, a docker network inspect operation was performed against the mini-siem-network. As can be seen from the Containers JSON list shown in Figure 3.4.2, both siem-db and siem-web belong to the same subnet (172.21.0.0/16) and have internal IP addresses (such as 172.21.0.2), which indicates that they can discover each other within the network. The above information clearly provides us with a Systematic Understanding of securely implementing professionally segregated cloud infrastructure following best cybersecurity practices [5].

```
khadija@Khadija: ~  
khadija@Khadija:~$ docker network inspect mini-siem-network  
[  
  {  
    "Name": "mini-siem-network",  
    "Id": "bdf10624ec81eff0c6a8412776e9368106e5fb24dca2928e302af86156e9e09d"  
  },  
  {  
    "Created": "2026-04-05T12:22:50.243388283+01:00",  
    "Scope": "local",  
    "Driver": "bridge",  
    "EnableIPv4": true,  
    "EnableIPv6": false,  
    "IPAM": {  
      "Driver": "default",  
      "Options": {},  
      "Config": [  
        {  
          "Subnet": "172.21.0.0/16",  
          "Gateway": "172.21.0.1"  
        }  
      ]  
    },  
    "Internal": false,  
    "Attachable": false,  
    "Ingress": false,  
    "ConfigFrom": {  
      "Network": ""  
    },  
    "ConfigOnly": false,  
    "Options": {},  
    "Labels": {},  
    "Containers": {  
      "6c1e108269f690d852f511d37094206bdf49d6091a6f24397908520b76287047":  
      {  
        "Name": "siem-db",  
        "EndpointID": "04240ce8cce0c9ccca8e9e09c7e7e5a7ba04c3d9c4f584795  
652e9318e8672a0",  
        "MacAddress": "16:e5:3c:8f:42:53",  
        "IPv4Address": "172.21.0.2/16",  
        "IPv6Address": ""  
      },  
      "d8ad78e891a9e021cd8700045defaacc68326b8ea5573217a58f7a878bc89068":  
      {  
        "Name": "siem-web",  

```

```

    "Containers": {
      "6c1e108269f690d852f511d37094206bdf49d6091a6f24397908520b76287047": {
        "Name": "siem-db",
        "EndpointID": "04240ce8cce0c9ccca8e9e09c7e7e5a7ba04c3d9c4f584795652e9318e8672a0",
        "MacAddress": "16:e5:3c:8f:42:53",
        "IPv4Address": "172.21.0.2/16",
        "IPv6Address": ""
      },
      "d8ad78e891a9e021cd8700045defaacc68326b8ea5573217a58f7a878bc89068": {
        "Name": "siem-web",
        "EndpointID": "fdfb9b514455355a5502a6cbe1869c991f2f4170c377726d238430b2a38371ef",
        "MacAddress": "56:75:c9:c7:8c:df",
        "IPv4Address": "172.21.0.3/16",
        "IPv6Address": ""
      }
    },
    "Status": {
      "IPAM": {
        "Subnets": {
          "172.21.0.0/16": {
            "IPsInUse": 5,
            "DynamicIPsAvailable": 65531
          }
        }
      }
    }
  }
}
]
khadija@Khadija:~$

```

Figure 3.4.2: Output of the network inspect command.

The process was further validated by directing the host computer's web browser to the mapped port, which is 8080 in this case. Figure 3.4.3 below shows how the SIEM dashboard loaded successfully. The successful loading of the SIEM dashboard indicates that the siem-web container is indeed receiving any external HTTP request through port 8080 and is sending the results after analyzing the data from the siem-db container.

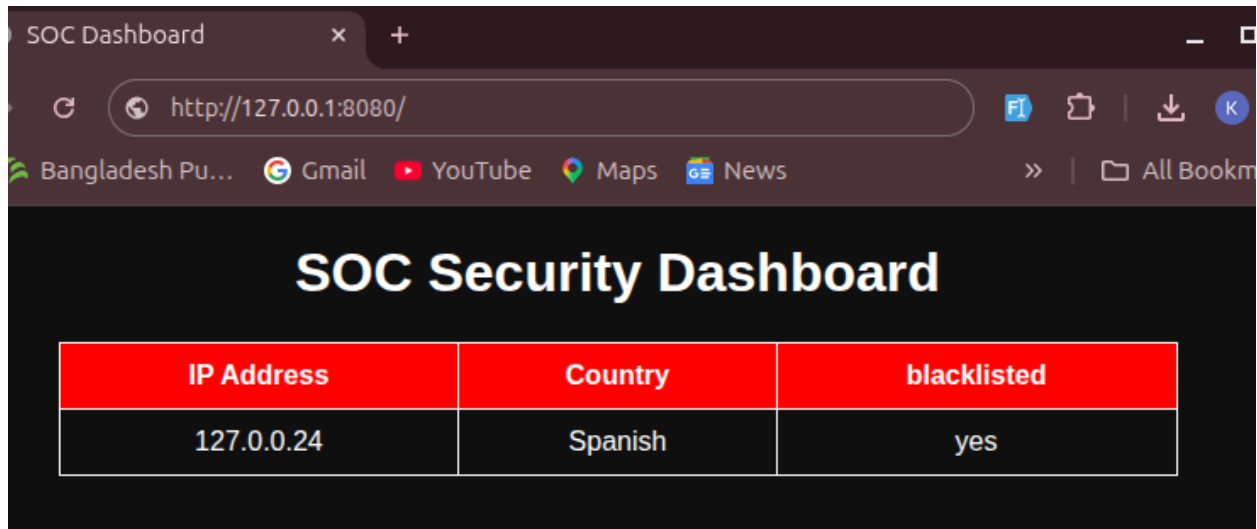


Figure 3.4.3: Successful client-side rendering of the Mini-SIEM Security Dashboard served through the Dockerized web tier.

4.0 Advanced Cloud Management Concepts

4.1 Critical Evaluation of Load Balancing

A load balancer is a primary building block in the architecture of cloud engineering that is intended to evenly distribute the network or application service traffic to a group of backend servers or containers. The primary goal of load balancing is to prevent any given resource from becoming a bottleneck, thereby ensuring optimal resource utilization, minimized response time, and the highest possible availability of the service [6]. A load balancer in the context of cloud-native applications is described as a reverse proxy that sits in front of the application service and provides a single point of entry for the clients, thereby hiding the complexity of the underlying infrastructure.

It is important to differentiate among various layers of the Open System Interconnection (OSI) protocol stack where load balancing takes place. Layer 4 (L4) Load Balancing happens at the transport layer, where routing decisions are based on IP addresses and TCP/UDP port numbers. This approach is highly efficient because it does not require examining actual data packets. Nevertheless, contemporary cloud-based systems heavily

rely on Layer 7 (L7) Load Balancing, also called Layer 7 Load Sharing or Application Load Balancing, which happens at the application layer. L7 balancers can make routing decisions based on data contained within a request, such as headers, cookies, or paths. This enables features such as session persistence or content-based routing to send requests for images to a storage-optimized cluster and API requests to a compute-optimized microservice.

A critical analysis of load balancing techniques indicates that load balancing is not just a distribution technique but also involves Health Monitoring. Contemporary load balancers continually perform health checks on backend servers. If a container or a VM fails, load balancers will redirect traffic to other healthy servers. This is the fundamental concept behind fault tolerance in clouds. However, it is important for engineers to understand the concept of a single point of failure. This means that if a load balancer fails, there will be no access to an application. Therefore, professional clouds use redundant load balancers in multiple Availability Zones to ensure global resiliency [6], [9]. For instance, Microsoft Azure achieves this using the Azure Load Balancer for high availability in the zones. This approach to load balancing is a demonstration of the application of high availability concepts for a postgraduate professional requirement.

4.2 Scalability: Vertical vs. Horizontal

Scalability refers to the architectural capacity of a system to increase capacity by adding resources to the system. This is a fundamental requirement of cloud-native applications in the modern world. It is critical to understand that cloud applications have two main strategies to scale in order to increase their capacity in response to increased demand and maintain their performance. These strategies are vertical scaling and horizontal scaling [11].

Scaling Up, also called Vertical Scaling, refers to the process of increasing the power of an existing server or instance by increasing the capacity of the

CPU, memory (RAM), and storage [13]. Though this is technically straightforward to implement, it has a critical disadvantage in that it has a hard limit based on the capacity of the physical hardware. Moreover, it is necessary to restart the instance in order to implement this kind of scaling, and this is a critical disadvantage of this approach to scaling in cloud computing.

On the other hand, Horizontal Scaling, also known as Scaling Out, involves increasing the pool of resources with more independent resources like Docker or Virtual Machines [11]. This method is the standard practice in the industry in cloud engineering because it provides infinite scalability and fault tolerance. In a horizontal scaling system, in case a container fails, the load balancer reroutes the request to other healthy containers, so there is no service outage to the end user [12], [13]. Horizontal scaling is achieved dynamically by cloud service providers through AWS Auto Scaling groups or Azure Virtual Machine Scale Sets.

A critical analysis of these ideas reveals that load balancing and scaling are 'complimentary concepts.' This means that a load balancer cannot function in an environment where there is only one server to which it can direct incoming requests, and on the other hand, a cluster of multiple containers cannot operate without a load balancer to direct incoming requests to it [6]. This ability to leverage these technologies to achieve 'Elasticity,' where infrastructure grows or shrinks in real-time in response to demand and optimizes costs, is an important skill set that is required in postgraduate professional practice.

4.3 Application Gateways and Security

Although regular load balancers perform their tasks satisfactorily at the transport layer, an Application Gateway is a concept for managing the cloud in a more sophisticated way, at the application layer, also known as Layer 7 of the OSI model. In enterprise environments, this is practically realized through services such as the Microsoft Azure Application Gateway or container-native solutions like NGINX Ingress. In a complex cloud

architecture, an Application Gateway acts like a load balancer, providing content-based routing. This feature enables the infrastructure to route traffic based on the content of an HTTP request, like the path of the request or the headers of the request. For example, traffic to `/images/*` can be routed to a container cluster optimized for storage, and traffic to `/api/*` can be routed to a compute-optimized backend.

From a security point of view, deploying an enterprise Application Gateway creates a critical advantage in terms of the Cognitive Skill of having a Web Application Firewall (WAF) protection feature. This is unlike traditional firewalls that rely on IP addresses and ports to filter out malicious traffic, but rather the WAF feature (such as the Azure WAF SKU) inspects the actual web traffic and protects against vulnerabilities such as SQL injection, cross-site scripting, and session hijacking [9]. This creates a central point of security enforcement for all microservices or containers, thereby eliminating malicious traffic even before it gets to the application level.

Moreover, these gateways are responsible for the management of the process known as SSL/TLS Termination. In this process, the computational load of decrypting the encrypted data is handled by the gateways rather than the individual backend containers. This Practical Skill ensures that the backend resources are free to concentrate only on the application logic, thereby improving the system's performance [7]. By incorporating all the above-mentioned security features and the complimentary concepts of load balancing and scalability, the Application Gateway ensures that the service is not only highly available but also robust against the ever-increasing cyber threats [6]. The implementation of a gateway ensures that the practitioner has a systematic understanding of how to provide a service that is not only secure but also professional-grade to a customer in an unpredictable professional environment.

5.0 Strategic Driving Forces in Cloud Expansion

5.1 Economic Drivers: CapEx to OpEx

The change from traditional on-premise infrastructure to cloud-based services is primarily driven by a fundamental change in financial models, from Capital Expenditure (CapEx) to Operational Expenditure (OpEx) . In traditional IT environments, significant capital expenditure is necessary to procure hardware, data center space, and associated cooling infrastructure. This traditional financial model often leads to over-provisioning, where an organization procures hardware that it does not necessarily need today, but will need tomorrow, wasting capital resources [1].

Cloud computing removes such huge costs by offering a pay-as-you-go approach. With the OpEx approach, a company can use computing as a utility, such as electricity or water, and only pay for what is actually needed at a given time. This approach removes a huge cost barrier for start-up companies and allows existing companies to use their resources for innovation rather than maintenance costs. Additionally, economic flexibility is also offered by the cloud through a concept called Rapid Elasticity to avoid costs by scaling up or down as needed to match demand levels [6].

A critical analysis of these economic factors shows that while OpEx provides liquidity and flexibility, it requires a sophisticated approach to Cloud Cost Management. This is because, without proper management, the ability to launch new containers or VMs in a cloud infrastructure can result in a phenomenon known as cloud sprawl, where costs get out of control due to unused resources that were not optimized. Thus, it is not just cost savings in the strategic expansion of cloud computing but also the Knowledge and Understanding of how to match infrastructure spend with business value and operations need [5], [12].

5.2 Serverless Functions (FaaS) vs. Containerisation

Another significant trend within cloud-based web services is the advent of serverless functions, or Function-as-a-Service (FaaS), with AWS Lambda

and Azure Functions being two prominent instances. At the graduate level, it is imperative to distinguish between serverless functions and containerization to throw further light on the drivers behind current trends in cloud computing. While both approaches aim at infrastructure abstraction, they operate at different levels of abstraction and distribution of responsibility. [5]

Containerisation, as seen with Docker, allows a developer to create a container for the entire application environment, including OS libraries and dependencies [4]. This provides the developer with the maximum degree of control but requires the developer to manage scaling policies. In serverless functions, the server is abstracted away. The developer simply provides the code for the function, with the cloud provider controlling all underlying infrastructure, scaling, and high availability [5].

A critical evaluation of these tools indicates the following economic and operational trade-offs:

- **Scaling Mechanics:** Whereas containers are normally subject to scaling in response to certain metrics, serverless functions scale automatically and instantly for every request received [1], [12].
- **Cost Structure:** Containers normally incur a permanent base cost due to the running instances (VMs) hosting them, while serverless functions incur zero cost when the function is not in use, thanks to the pay-per-execution feature [5].
- **Execution Limits:** Serverless functions are normally stateless and are subject to time constraints, making them inappropriate for long-running tasks, which are better handled by persistent Docker containers [3], [5].
- **Startup Latency:** Serverless functions normally incur cold starts when the functions are not frequently requested, unlike a running container, which is always ready to send a response to requests received [2].

Ultimately, the choice between serverless architecture and containerization depends on the specific needs for flexibility and cost efficiency. Serverless architecture is best for unpredictable workloads such as image processing or API triggers, but containerization is best for complex migration scenarios involving monolithic to microservices architecture, where there is a strong need for environmental controls to manage such a migration process [3], [4].

5.3 Operational Flexibility and Business Agility

However, the rationale for the shift towards cloud-native platforms is not only driven by cost factors but is further enhanced by the need for increasing operational flexibility and business agility. In a traditional IT setup, the speed at which new feature sets are introduced to the market is often challenged by the physical nature of purchasing hardware and then configuring it. Cloud engineering, through containerization and orchestration, allows organizations to deliver a model of infrastructure as code, thereby allowing for speed-to-deployment capabilities that react to business needs in near real-time [1].

This flexibility is primarily driven by the portability of Docker containers. This is because, by bundling all the dependencies within the container, it can move from the local Ubuntu environment, the testing cluster, to the production environment on Azure or AWS without requiring reconfiguration [4]. This capability helps mitigate the technical debt arising from bugs specific to environments, thereby allowing development teams to focus on innovation, not debugging environment differences. In addition, the ability to implement Blue-Green deployments or Canary releases, where the new version of an application is rolled out while keeping the previous version active, acts as a fallback mechanism that helps prevent outages during application updates [2], [3].

A detailed analysis of the level of agility within an organization reveals that this agility requires a cultural shift towards a DevOps approach. The automation process, from building the image and pushing it out to DockerHub to ultimately deploying it behind an Application Gateway, requires a systemic understanding of the entire stack. While the cloud provides the tools to deliver this agility, the driving force behind this is the ability of the organization to deploy these tools to deliver a competitive advantage through speed and reliability [5], [12]. Through attaining a mastery of this learning, the postgraduate practitioner is able to demonstrate the skills required to deliver digital transformation strategies within inherently unstable professional contexts.

6.0 Conclusion

This report provides a systematic assessment of the technologies and strategic factors that define modern cloud engineering, bridging the gap between theory and application in postgraduate education. Through a critical analysis of the underlying principles of virtualization, it is evident that while traditional virtual machines offer strong hardware-level security, there is significant resource overhead and latency in comparison to the process-level security offered by containerization. The application examples in Dockerfile construction, distribution via Docker Hub, and volume management highlight how these tools facilitate environmental consistency and rapid elasticity in professional environments.

Moreover, the research into advanced cloud management found that load balancing, scalability, and application gateways need to be integrated to ensure high availability and security in a changing professional world. This technology has been supplemented by the strategic driving forces behind the growth of clouds: the economic shift from a CapEx to an OpEx model, allowing organizations to view their infrastructure as a scalable utility.

The comparative analysis of serverless functions and containerization provides a better understanding of the ever-changing landscape of cloud abstraction, where the choice between granular environmental control and

overall infrastructure management is driven by specific business agility needs. In conclusion, it can be stated that mastery of the above-stated Cloud Engineering Principles is a prerequisite for the effective deployment of robust, efficient, and secure online services. While the industry is moving towards more automated and abstracted architectures, the ability to autonomously manage complex tasks is a basic skill for advanced users.

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8.0 Appendix: Video Demonstration Link

The video demonstration presented below was produced as real-life visual proof of the cloud engineering approach described within Section 3.0 of the present report. This video demonstrates the full process of creating a Mini-SIEM application in the form of a Docker container.

Demonstration Video URL: <https://youtu.be/ZliRMAFuc2k>