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Design and Implementation of a Cloud-Native Web API for Third-Party Integrations

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Master in Computer Engineering

Supervisors:

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Iscte – Instituto Universitário de Lisboa

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September, 2025

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TECHNOLOGY
AND ARCHITECTURE

Department of Information Science and Technology

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Acknowledgment

This dissertation represents an end to a long academic journey. I am grateful for my family and friends, who gave me their unconditional support throughout this time. I want to give a special tribute to my father, who I know would be very proud of this achievement. I would also like to thank my supervisors, Doctor Ana Maria de Almeida and Doctor Carlos Coutinho, for their guidance and patience.

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Resumo

O desenvolvimento de aplicações *web* de nível empresarial que necessitam de se integrar com diversos serviços externos levanta desafios arquiteturais significativos, especialmente no que diz respeito à escalabilidade e à resiliência. As arquiteturas de *software* monolíticas tradicionais têm dificuldade em dar resposta a estes problemas, uma vez que possuem uma menor tolerância a erros e uma escalabilidade limitada, entre outras desvantagens. Esta dissertação investiga a hipótese de que uma arquitetura de microsserviços hospedada na *cloud*, e que emprega o padrão de *API Gateway*, é a abordagem mais adequada para este tipo de aplicação. Para confirmar esta hipótese, foi desenhada e implementada uma *API web* como prova de conceito, usando a indústria de transporte de fretes como domínio de negócio. Esta *API web* integrou duas *APIs* externas: a WebCargo para transporte aéreo e a Cargofive para transporte marítimo. A solução foi desenvolvida com recurso à *framework* ASP.NET Core 8.0 e hospedada na platforma *cloud* Microsoft Azure, utilizando vários serviços para a *API Gateway*, a hospedagem de microsserviços, as bases de dados, entre outros. A eficácia da *API web* implementada foi demonstrada pelo cumprimento de vários requisitos de *software*, abrangendo funcionalidade, resiliência, segurança, desempenho e escalabilidade. Os resultados suportam a hipótese mencionada anteriormente. Deste modo, conclui-se que a arquitetura proposta oferece a escalabilidade e a resiliência necessárias para aplicações *web* de grande escala com necessidades complexas de integração externa. Este trabalho contribui com um estudo de caso prático e extensivo, diferindo assim da maioria da literatura encontrada sobre o tema.

Palavras Chave: *API Web*, *Microsserviços*, *Cloud Computing*, *Desenvolvimento de Software*, *Arquitetura de Software*

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Abstract

Developing enterprise-level web applications that need to integrate with heterogeneous third-party services raises significant architectural challenges, especially regarding scalability and resilience. Traditional monolithic software architectures struggle to address these difficulties because they have a lower tolerance for errors and limited scalability, among other drawbacks. This dissertation investigates the hypothesis that a cloud-hosted microservices architecture, employing the Application Programming Interface (API) Gateway pattern, is the most suitable approach for this type of application. To confirm this hypothesis, a proof-of-concept web API was designed and implemented with freight forwarding as its business domain. This web API integrated two distinct external APIs: WebCargo for air transport and Cargofive for sea transport. The solution was developed using the ASP.NET Core 8.0 framework and hosted on Microsoft Azure, utilizing various Platform as a Service (PaaS) services for the API Gateway, microservice hosting, data persistence, and more. The effectiveness of the implemented web API was demonstrated by meeting various software requirements, covering functionality, resilience, security, performance, and scalability. The results support the previously mentioned hypothesis, concluding that the proposed architecture provides the necessary scalability and resilience for large-scale web applications with complex external integration needs. This work contributes a practical, extensive case study, thus differing from most of the noted literature on the topic.

Keywords: *Web API*, *Microservices*, *Cloud Computing*, *Software Development*, *Software Architecture*

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List of Acronyms

API: Application Programming Interface

AWS: Amazon Web Services

CI/CD: Continuous Integration/Continuous Delivery

CORS: Cross-Origin Resource Sharing

CPU: Central Processing Unit

CRUD: Create Read Update Delete

DNS: Domain Name System

DSRM: Design Science Research Methodology

DTO: Data Transfer Object

ECS: Elastic Container Service

GB: Gigabyte

GiB: Gibibyte

GCP: Google Cloud Platform

HTTP: Hypertext Transfer Protocol

HTTPS: Hypertext Transfer Protocol Secure

IaC: Infrastructure as Code

IATA: International Air Transport Association

IaaS: Infrastructure as a Service

IDE: Integrated Development Environment

IT: Information Technology

IS: Information System

JSON: JavaScript Object Notation

JWT: JSON Web Token

KB: Kilobyte

LCL: Less than Container Loaded

OAuth: Open Authorization

OIDC: OpenID Connect

ORM: Object Relational Mapping

OS: Operating System

PaaS: Platform as a Service

PRISMA: Preferred Reporting Items for Systematic reviews and Meta-Analyses

RBAC: Role-Based Access Control

RDS: Relational Database Service

REST: Representational State Transfer

RPC: Remote Procedure Call

SaaS: Software as a Service

SOA: Service-Oriented Architecture

SPA: Single-Page Application

SQL: Structured Query Language

UI: User Interface

URL: Uniform Resource Locator

vCPU: Virtual Central Processing Unit

VNet: Virtual Network

VM: Virtual Machine

XML: eXtensible Markup Language

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CHAPTER 1

Introduction

1.1. Context

Digital transformation is changing the way businesses communicate with a network of partners and third-party service providers. This shift is powered by Application Programming Interfaces (APIs), which enable software systems to communicate with each other smoothly [1]. However, this increased connectivity fuels the need to aggregate and integrate heterogeneous external services into a unified platform. Companies seeking to build platforms must often interact with several third-party APIs that vary widely in their design, data formats, communication protocols, and reliability. This inconsistency creates complexity, making it more difficult to build systems that are scalable, maintainable, and resilient [2].

The freight forwarding industry serves as a case study for this integration challenge. Many companies in this industry are undergoing digitalization to meet growing client demands and remain competitive [3]. Traditional freight forwarders have been lagging behind due to an overreliance on manual processes. This gives rise to digital freight forwarders that provide more advanced and automated services, integrating several carrier providers, often across multiple modes of transport [4].

Devlop[1], an Information Systems (ISs) company from Portugal that specializes in developing software solutions for the transport and logistics sectors, proposed creating a web application to provide real-time freight quotes from multiple carriers to customers. To this effect, two external APIs would be integrated: WebCargo[2] (for air transport) and Cargofive[3] (for sea transport). A traditional monolithic software architecture is not suitable for this as the application grows, since an issue in one integration could hinder the entire system. This establishes the need for a more robust and scalable approach.

This dissertation proposes a conceptual framework to address these integration and scalability challenges, which may be present in other projects with similar characteristics in any industry. To do so, it uses a proof-of-concept implementation. The defining factors of this implementation are the microservices architecture, which increases resilience and scalability, and the cloud platform, which offers a wide range of components and services that facilitate deployment, management, and scaling of the proposed software solution.

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[1] Devlop, `https://devlop.systems/`, (accessed 16 Aug. 2025)
[2] WebCargo, `https://www.webcargo.co/about/`, (accessed 19 Aug. 2025)
[3] Cargofive, `https://cargofive.com/`, (accessed 19 Aug. 2025)

1.2. Motivation

The dissertation aims to address the architectural challenges faced when integrating various third-party APIs by investigating a cloud-native microservices approach. The application proposed by Devlop faces these difficulties. The development of effective and scalable software is crucial to the success of modern freight forwarding digital platforms, especially in a time when choosing the right technology to address all user requirements is becoming more difficult [5].

Even though the theoretical benefits of microservices and cloud computing are well-documented in scientific literature, there is a lack of practical case studies. The few studies that go beyond theory tend to focus on specific and isolated architectural features rather than presenting a complete framework for building an entire application. This work moves the discussion from theoretical advantages to a complete implementation, providing a concrete case study to the field of software architecture.

1.3. Research Questions

Based on the considerations presented in Section 1.2, this research presents a conceptual framework for developing cloud-native web APIs that integrate and aggregate external services. This study is guided by this research question:

Research Question. How to design and implement a software architecture that meets the requirements of complex web applications integrating several external APIs?

The research question leads the following hypothesis, which will be studied in this paper:

Hypothesis. A microservices architecture, orchestrated through an API Gateway and deployed to a cloud platform, is the most suitable choice for complex web applications integrating multiple external APIs.

1.4. Research Methodology

This dissertation follows the Design Science Research Methodology (DSRM), a six-step research approach often used to create IS-related artifacts such as models, methods, design theories, or, in this context, an instantiation [6].

This dissertation adheres to the "Design & Development Centered Initiation" entry point shown in Figure 1.1, as the first and second steps have already been presented in Chapter 1.

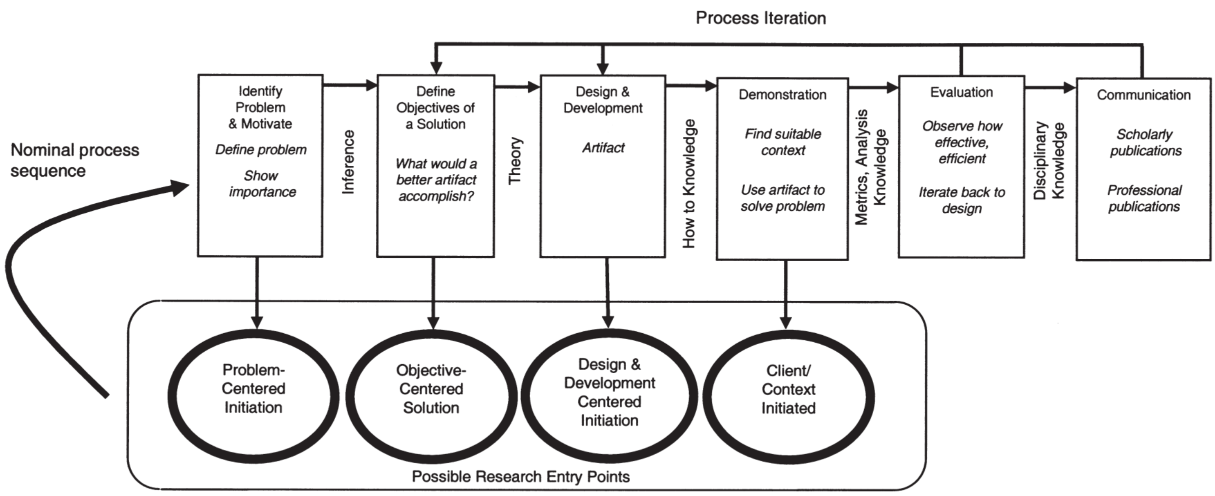

FIGURE 1.1. Design Science Research Methodology [6]

The following list briefly explains what each step entails and where it is located in this paper:

Problem Identification and Motivation: Section 1 highlights that despite APIs being crucial for business connectivity, integrating multiple external APIs creates significant challenges for scalability and reliability. A freight forwarding industry project is introduced as a case study. The motivation expressed in Section 1.2 is to offer a solution to these problems and contribute with a complete case study to the scientific literature.

Definition of Solution Objectives: The goals of the solution proposed in this dissertation are introduced in Section 1.2. In Section 4.1, all requirements are precisely listed and defined, further clarifying the objectives of the solution.

Design and Development: Chapter 4 details the architecture of the entire solution, while Chapter 5 reveals important parts of the implementation process.

Demonstration: Chapter 5 demonstrates a working artifact deployed on a remote cloud.

Evaluation: Chapter 6 evaluates the developed instantiation considering its reliability, performance, predicted cost, and efficacy.

Communication: This dissertation itself serves as a means of communication, intended for both academic and business audiences. Chapter 7 summarizes the most relevant findings.

1.5. Document Structure

This document is divided into seven chapters.

Chapter 1 introduces the context, motivation, research questions, and the research methodology of this dissertation.

Chapter 2 explains the literature search methodology, including the strategy for identifying relevant literature and the papers included in the review.

Chapter 3 presents a literature review that offers a theoretical background on the main topics relevant to this dissertation.

Chapter 4 details the design and architecture of the proposed solution.

Chapter 5 demonstrates and discusses the implementation of the proposed solution.

Chapter 6 evaluates the implemented solution on correctness, estimated cost, performance, and efficacy.

Chapter 7 concludes the dissertation, highlighting the main findings, limitations, and suggesting future work.

CHAPTER 2

Literature Search Methodology

This chapter describes the methodology used to gather relevant literature for the review presented in Chapter 3, along with its results. The search process follows the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines, as explained in Section 2.1.

2.1. PRISMA-S

Because DSRM does not define a method to search scientific literature, PRISMA-S was used as the basis for the literature search. PRISMA is a complete set of guidelines used to improve the reporting of systematic literature reviews, promoting rigor. PRISMA-S (or PRISMA-Search) is a reporting guideline that extends PRISMA, contributing with a detailed checklist specifically for reporting literature search methods.

2.2. Information Sources

The b-on[1] platform was used for the PRISMA-S literature search. b-on is a library that aggregates multiple databases[2], including IEEE, Web of Science, and Elsevier. This agglomeration removes the need to search individual databases separately.

2.3. Search Strategies

The search was performed using the exact query shown below, where "TI" and "AB" stand for "title" and "abstract", respectively:

```
(TI ("web API*" OR "backend*" OR "web application*")
OR AB ("web API*" OR "backend*" OR "web application*"))
AND TI (Architecture OR Develop* OR Design)
AND TI (Cloud* OR Microservice*)
```

The following search filters were applied in sequence:

(1) The document must be from 2015 or later.
(2) The document must be peer-reviewed.
(3) The document must be written in English or Portuguese.

[1] b-on, `https://www.b-on.pt/en/`, (accessed 16 Aug. 2025)
[2] b-on, "Collections", `https://www.b-on.pt/en/collections/`, (accessed 16 Aug. 2025)

2.4. Search Results

Once the search query was run and all aforementioned filters were applied, all filtered documents went through a process to determine whether they would be included in the final review. That process is shown in Figure 2.1.

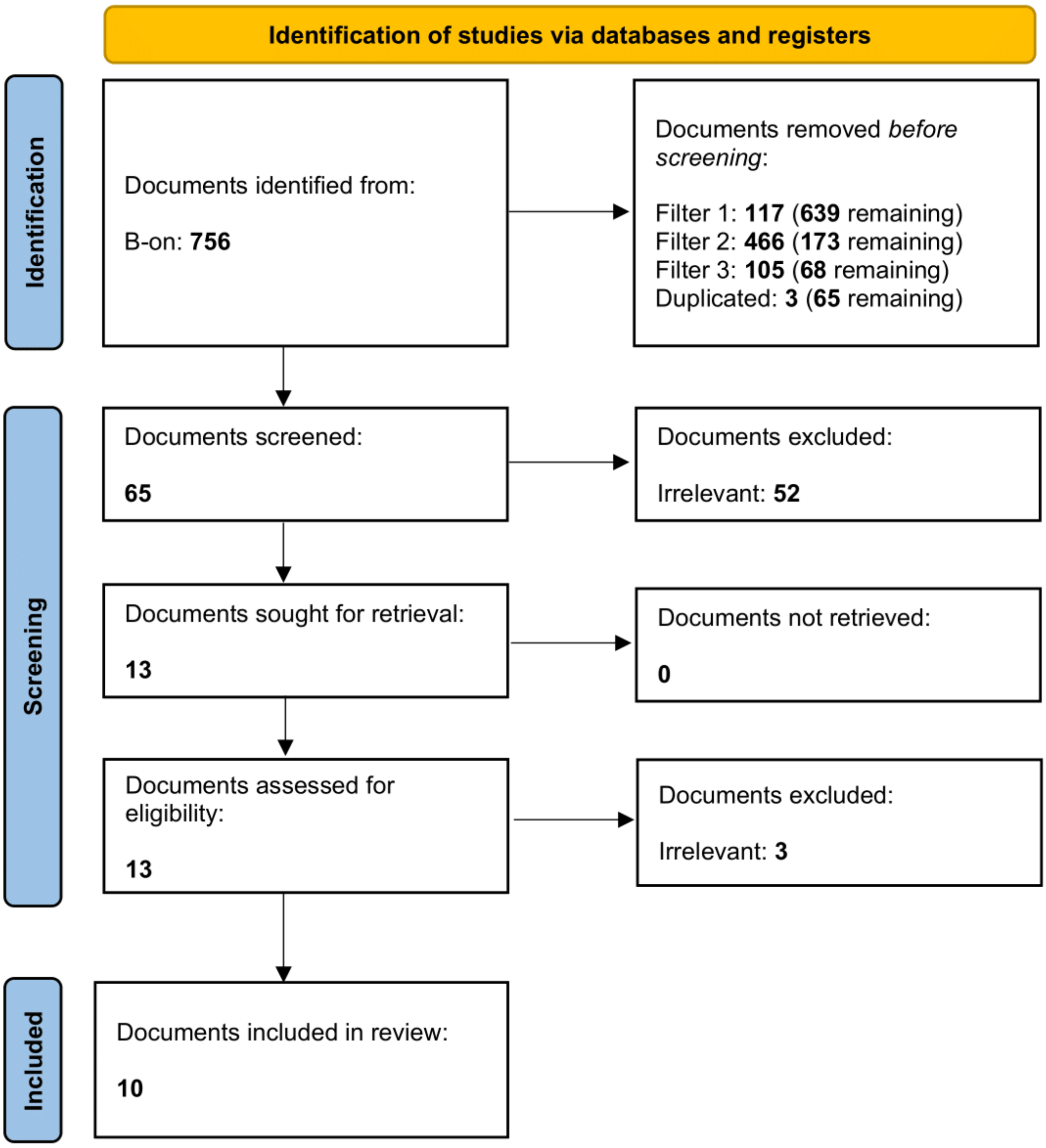

FIGURE 2.1. Literature Search Flow Diagram

The search query identified 756 documents. Upon filtering and deduplication, 65 documents remained. These documents went through a screening process that involved reading their titles and abstracts to determine their relevance. After screening, 13 documents were left. The eligibility of these documents was then evaluated by reading their full text to verify their relevance more rigorously. Only 10 documents were included in the final review, some of which did not present a complete architectural approach for web APIs or web applications. This outcome matches the lack of literature on this topic mentioned in Section 1.2.

2.5. Further Search

The 10 resulting documents gathered in Section 2.4 did not offer a comprehensive and varied view of web applications or web APIs. Therefore, additional literature searches were conducted based on topics present in those 10 documents, namely Monolithic and Microservice Architectures, Cloud Computing, Authentication and Authorization, Containerization, and Web API Frameworks.

Furthermore, a literature search on freight forwarding was done to better understand the business domain of the web API that will be developed. To perform this further research, b-on, Google Scholar, and websites from authoritative sources were accessed.

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CHAPTER 3

Literature Review

Based on the literature search methodology presented in Chapter 2, this chapter provides a theoretical background on the main topics relevant to this dissertation.

3.1. Freight Transportation Overview

Freight transportation is defined as the flow and storage of goods throughout a supply chain, from an origin to a destination. To achieve this, several stakeholders contribute to the process [7, 8]. In this project, since the application to develop will be administered by a freight forwarding company, the most important ones are the following:

Shipper: The person or company that sells goods to be sent from one location to another. They are the initiators of the whole process, generating the demand for freight transportation [7].

Carrier: The party that provides the transportation service of goods, such as a shipping or airline company [7].

Freight forwarder: The intermediary entity between the shipper and the carriers. It organizes and coordinates the shipment of goods on behalf of its customer seller (the shipper). They are usually responsible for selecting and contracting with appropriate carriers, container consolidation, shipment tracking, transshipment, negotiating delivery terms and freight rates, among other activities [7, 9].

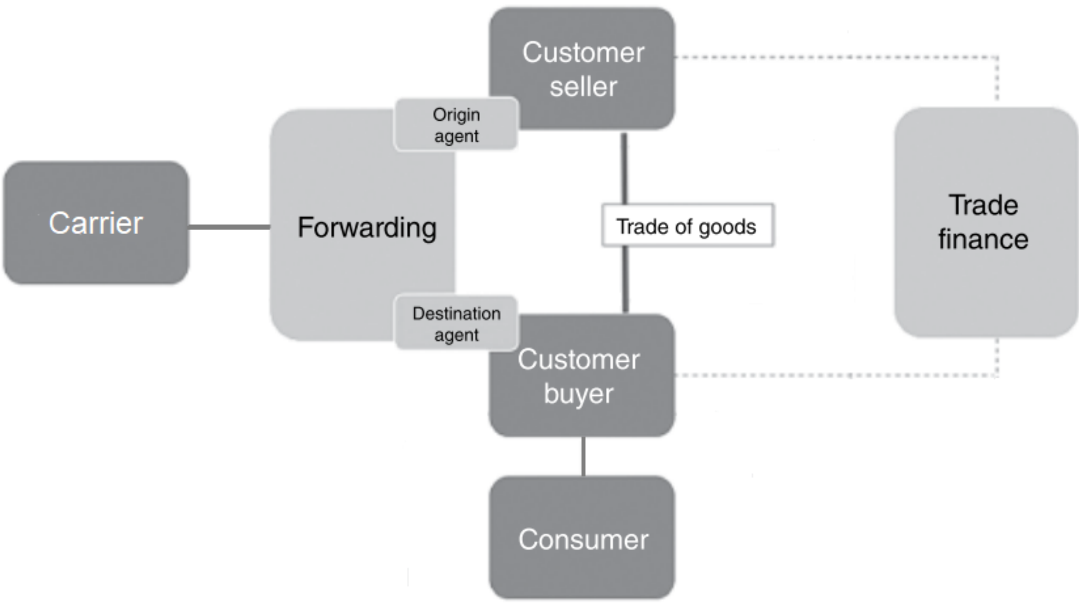

Figure 3.1. Freight Forwarding Stakeholders, adapted from [6]

Understanding freight rates is relevant for this project, since responding to quotation requests from shippers is one of its goals. The freight rate is the definite cost a carrier charges to transport a specific cargo from one location to another. This cost depends on factors like the cargo's weight, volume, mode of transport, and travel distance. A freight quote is a comprehensive estimate of the total cost to transport a particular cargo from an origin to a destination, which includes the freight rate and any additional fees [7, 10, 3, 11].

Various transport modes may be used, including air, sea, waterway, road, and rail. Multiple modes of transport may also be used throughout the journey, a practice known as multimodal transport. In 2019, 70% of the global freight (measured in tonne-kilometers) was done by ships, followed by road vehicles with 22%, trains with 7%, and air vehicles with less than 1% [12].

Although shippers have the option to work directly with carrier companies, many enterprises, especially small to medium-sized ones, resort to the services provided by freight forwarders. These enterprises tend to deliver Less than Container Loaded (LCL) cargo, which requires consolidation to achieve cost-efficient transportation. The expertise of freight forwarders and their wide network of carriers help shippers find the most appropriate offers and reduce freight rates, decreasing the total delivery price [9].

3.2. Web APIs Overview

An API is a set of rules and specifications that define how software components or applications should interact with each other. In this dissertation, web APIs are specifically defined as server-side (backend) web APIs, which act as an exposed interface for a web server. They allow client systems like web browsers and mobile applications to interact with the server's resources without needing to know its internal structure and implementation [13, 14, 15].

Essentially, a web API acts as an abstraction layer that facilitates communication through a request-response cycle. A client sends a request to a specific endpoint on a server, which contains details about the desired operation and any necessary data. The server processes the request and returns an Hypertext Transfer Protocol (HTTP) response. This response contains a status code indicating success or failure and, depending on the request, a body with the requested data, often formatted in JavaScript Object Notation (JSON) or eXtensible Markup Language (XML). This client-server relationship forms a complete web application that end-users can use [13, 14, 15].

Web APIs specifications come in different architectural styles, which define the syntax and structure of the client-server interactions. These include:

Representational State Transfer (REST): The most widely used architectural style for API development. It organizes its operations around resources, which may be any information that can be identified or named within the context of a web application, such as users, files, purchases, events, etc. REST APIs generally use standard HTTP methods to perform Create Read Update Delete (CRUD) operations on these resources: "GET" to read, "POST" to create, "PUT" and "PATCH" to update, and "DELETE" to delete [14, 16, 17, 15].

GraphQL: This architecture allows clients to specify the exact structure of the data they require. Unlike REST, which often requires multiple requests to different endpoints to gather related data (under-fetching) or returns more data than needed (over-fetching), GraphQL exposes a single endpoint. This reduces the amount of data transferred over the network, at the cost of development complexity [14, 16].

Remote Procedure Call (RPC): RPC APIs are function-based, unlike REST and GraphQL APIs, which are centered on resources and data, respectively. Each endpoint these APIs expose are associated with a particular function on the server side. This architectural style can offer high performance with its deserialization method, as well as bidirectional and real-time streaming communication support. However, it can be harder for consumers of these APIs to find the desired endpoints, as it is less standardized [14, 16].

3.3. Web API Security: Authentication and Authorization

Web APIs may expose confidential operations and data, requiring robust security measures. These measures can be understood as two layers: authentication and authorization. Authentication is the process of identifying users and verifying if they are indeed who they claim to be. Authorization is processed after authentication and determines the actions that a specific user is allowed to perform [18, 19].

There are several security protocols and mechanisms to address authentication and authorization, including:

Open Authorization (OAuth) 2.0: The OAuth protocol is an authorization framework that allows users to access backend services without sharing their credentials. In a web application, when a user clicks the login link, the client directs the user to an authorization server where they authenticate. Once the user is authenticated, the authorization server redirects the user back to the client with an authorization code, which is exchanged for an access token. The client includes this token whenever it sends a request to the resource server. The server validates it and uses it to determine what the user is authorized to do [18, 19].

JSON Web Token (JWT): A JWT is a compact standard for securely transmitting information between parties as a JSON object. This information, known as claims, can be verified and trusted because it is digitally signed. JWTs can be used as the format for access tokens in OAuth 2.0 flows, and may contain additional information about the user [18, 19, 17].

OpenID Connect (OIDC): OIDC is an authentication layer built on top of the OAuth 2.0 framework that guarantees users have a single identity for multiple services or applications. While OAuth 2.0 provides delegated authorization, OIDC adds authentication through ID tokens, allowing clients to verify the identity of the user based on the authentication performed by an authorization server [19].

API Keys: API keys are a simple authentication method where a unique string of characters, the API key, is assigned to a user or application. API keys do not distinguish between users, providing little flexibility of access control. [18].

Although other security mechanisms were found in literature, these were identified as the most relevant to the security requirements of modern and distributed web APIs [19]. API keys were mentioned despite their low granularity because they are the authentication method of the two external APIs mentioned in Section 1. All these mechanisms are significant to the architecture detailed in Chapter 4.

3.4. Web API Frameworks

Software frameworks are a set of reusable libraries and tools that create a structure for software development. By providing generic functionality, they reduce complexity and repetitiveness, enabling developers to write less code while achieving higher quality results [20].

In 2024, Stack Overflow conducted a survey to assess the popularity of several technologies and tools among software developers. In this survey, participants were asked "Which web frameworks and web technologies have you done extensive development work in over the past year, and which do you want to work in over the next year?". 38,132 professional developers responded. Figure 3.2 shows the results, including only the top seven backend frameworks [21].

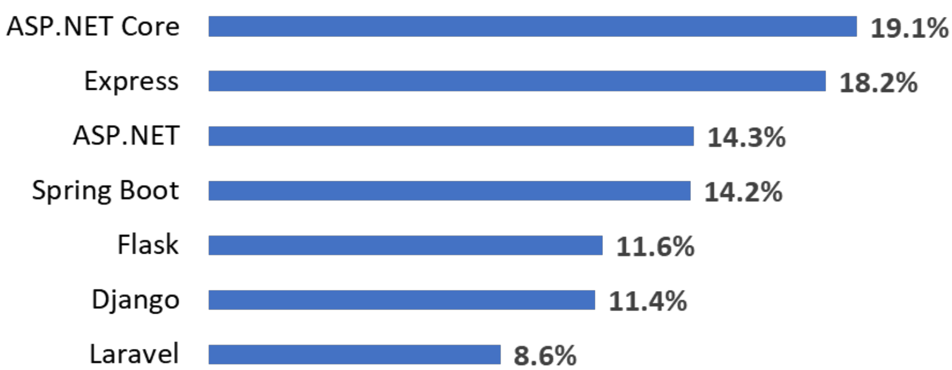

Figure 3.2. Web API frameworks used by professional developers, adapted from [21]

The web API frameworks present in Figure 3.2 are the following:

ASP.NET Core/ASP.NET: ASP.NET Core is a high-performance and feature-rich framework developed by Microsoft. It is the successor to ASP.NET. Compared to its predecessor, ASP.NET Core offers many additional features and capabilities like increased performance, cross-platform compatibility, and native support for client-side development [22, 23]. This framework uses the C# programming language, demonstrating faster request processing compared to Django, Laravel, and frameworks based on Node.js. [24, 20, 23]. ASP.NET Core is suitable for computationally-intensive or enterprise-scale applications due to its high performance and scalability [25].

Express: A flexible and minimalist framework that uses the Node.js environment, allowing server-side JavaScript execution, which explains its high popularity [26]. Due to its event-driven single-threaded nature, it is more resource-efficient than Django and ASP.NET Core, for example [24, 26]. However, it is slower in processing CPU-intensive requests compared to ASP.NET Core and Spring Boot [24, 26, 27]. It also lacks some features natively present in other frameworks [28]. Still, Express is particularly effective for I/O-intensive applications, like chat and streaming applications [26, 29].

Spring Boot: An opinionated and feature-rich Java-based framework focused on ease of development. It reduces the need for configuration and generic code by providing starter dependencies, auto-configuration, default components, and more. It also offers real-time health status monitoring, metric reports, and traffic tracking. Spring Boot is especially suited for large-scale enterprise applications that use microservices [28, 29, 23].

Flask: A lightweight and minimalist Python microframework. It is quite flexible and facilitates quick development, requiring no specific tools or libraries. Its design supports projects that start small and can be extended easily and customized as needed. Consequently, Flask is best suited for building resource-efficient microservices and smaller applications that require a high level of control. [28, 29].

Django: A scalable and feature-rich Python framework. It has a comprehensive list of features, including an Object Relational Mapping (ORM) tool that simplifies database operations, and an automatically generated administrator interface [28, 29, 30]. One of its drawbacks is slower request processing compared to other frameworks like ASP.NET Core and Spring Boot [24, 27]. Despite that, it is suitable for both small-scale and large-scale applications [28, 29].

Laravel: A feature-rich framework built on the PHP programming language. Its toolset includes an ORM database tool, versatile database migrations, and built-in task queuing and scheduling. This framework prioritizes concise and well-organized code. Laravel is suitable for both small projects and large-scale applications [28, 20, 31].

3.5. Monolithic *vs.* Microservices Architecture

The architectural design of a web API is a decision that significantly impacts its development, deployment, scalability, and maintenance. When developing web APIs, two dominant patterns emerge: the traditional monolithic approach and the modern microservices approach. Several papers highlight their benefits and drawbacks [2, 32, 33, 34].

3.5.1. Monolithic Architecture

A monolithic architecture is a traditional model for software development in which the entire or most of the application is built as a single, tightly coupled unit. For a web API, this means that all endpoints and their underlying logic are present within a single codebase and deployed as one unit [32, 33, 34, 35, 36, 37].

The main advantages of this approach are due to its basic nature. It offers simplicity of development, especially at the beginning of a project, because there is no burden from managing a distributed system. This centralized structure can also lead to improved performance, since calls between different components are direct function calls rather than network requests. A monolith is also easier to test, as requests tend to undergo fewer jumps between software components [23, 32, 33, 34, 35, 36].

However, the monolithic model can be resource-inefficient since it is impossible to scale individual components independently. This architecture also imposes one particular technological framework on the entire application, reducing flexibility. In addition, because even a small change or issue can require the entire application to be recompiled and redeployed, it lowers resilience and deployment speed. All these issues only worsen as the application grows, leading to decreased scalability and maintainability, as well as possibly negating some of its advantages [32, 33, 34, 35, 36, 38].

Figure 3.3 illustrates a monolithic architecture.

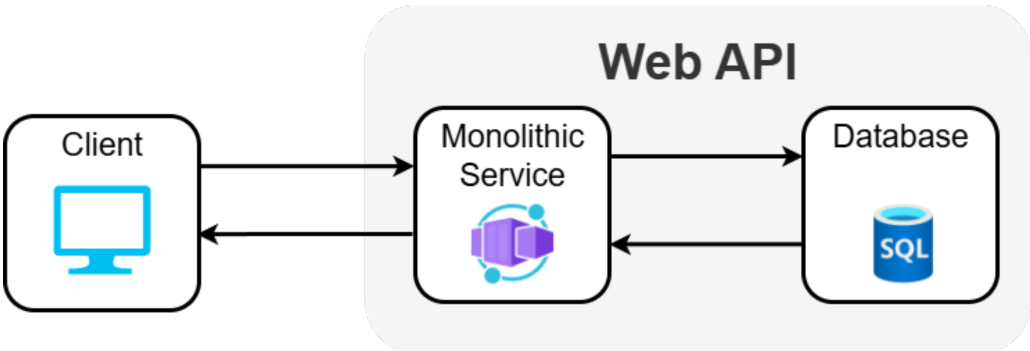

FIGURE 3.3. Example of a Monolithic Architecture

3.5.2. Microservices Architecture

A microservices architecture follows a Service-Oriented Architecture (SOA), structuring an application as a collection of small and loosely coupled services. Each service is self-contained, responsible for a specific business goal, and may communicate with other services [32, 33, 34, 39, 35, 36].

The microservices architecture offers superior scalability, as each service can be scaled independently based on its specific load, which is a highly efficient model for cloud-based deployments. This decoupling also allows a heterogeneous technology stack, for example, one service may use the ASP.NET Core framework while another uses the Spring Boot framework. Furthermore, this type of architecture is more resilient, as the failure of a single service does not necessarily compromise the entire application. Additionally, this architecture improves maintainability by breaking a large application down into smaller and more understandable codebases. Developers can work on individual services, allowing them to develop, deploy, and update their components autonomously [32, 33, 34, 39, 35, 36, 38].

However, the microservices pattern introduces some challenges. One drawback is the increased implementation effort, since developers must implement mechanisms for inter-service communication. This leads directly to communication and network complexity. Instead of simple function calls, services must communicate over a network, introducing considerations of latency, security, and fault tolerance [32, 33, 39, 35, 36, 38, 37].

To address some challenges inherent to the microservice architecture, the API Gateway pattern is often recommended. In this pattern, an API Gateway acts as an intermediary for all client requests, simplifying the client-side logic. Instead of clients needing to know the addresses of and communicate with multiple services, they make requests to the gateway only. The gateway then routes requests to the appropriate microservice, and can also aggregate responses from multiple services into a single response. It may handle concerns such as authentication and rate limiting as well [32, 33, 39, 36].

Regarding data management, multiple approaches may be applied when dealing with microservices, ranging from a single shared database for all services, to one database per service. Sharing a single database is simpler and facilitates data integrity, but is less scalable and flexible. In contrast, using one database per service offers greater scalability and flexibility, but increases complexity and adds the challenge of maintaining data integrity between services [32, 39, 36].

Figure 3.4 shows an example of a microservice architecture adhering to the API Gateway and database-per-service patterns.

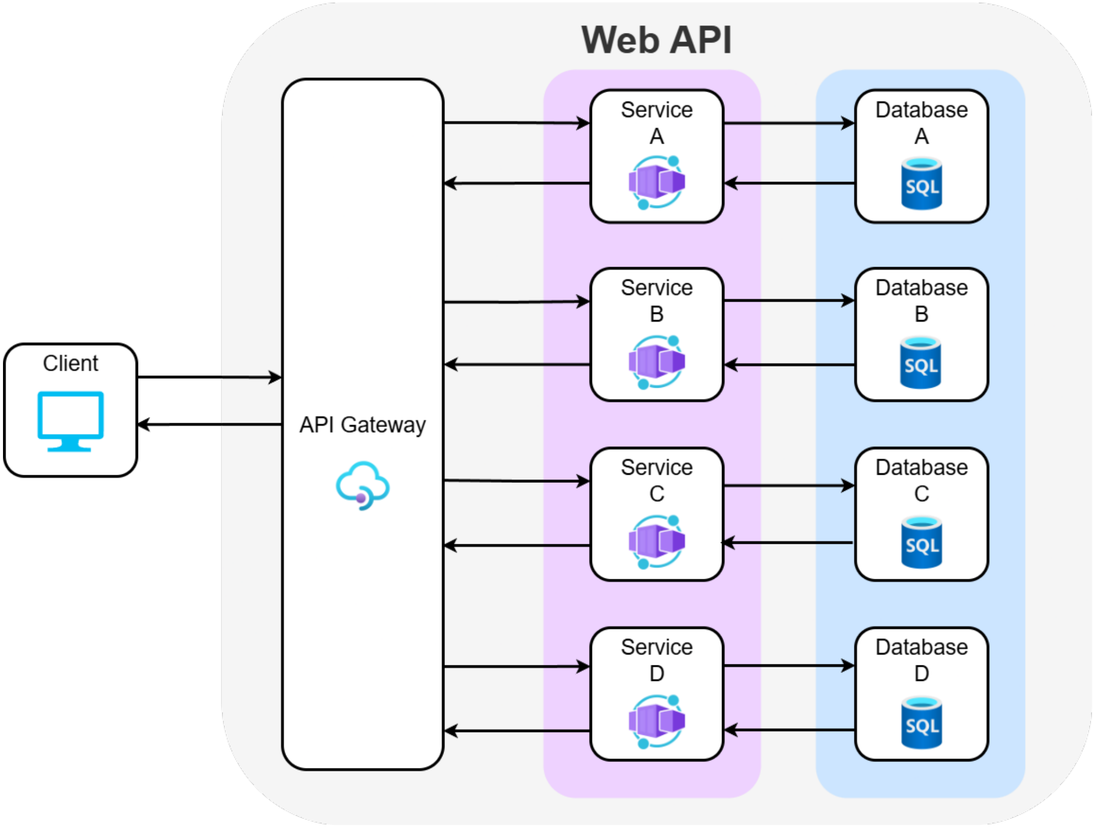

FIGURE 3.4. Example of a Microservices Architecture

3.6. Cloud Computing

Cloud computing is the provision of on-demand Information Technology (IT) services to customers over the Internet. These services may consist of software applications, databases, analytics, servers, and more. The resources are hosted on a remote server (the "cloud") located in a provider's data center, and accessible through a web browser [35, 40, 41, 42].

Cloud services can be divided into three distinct models:

Infrastructure as a Service (IaaS): Provides processing power, storage, and network capabilities through a Virtual Machine (VM). The customer is responsible for the Operating System (OS), runtimes, applications, and data. This model is quite flexible and is suitable for companies that want to improve the reliability and scalability of their infrastructure [35, 40, 43, 44].

Platform as a Service (PaaS): Offers an environment to build, deploy, and run applications without managing the associated hardware and software infrastructure. The customer can focus on developing applications and handling data, making this model is useful for software engineers and developers [35, 40, 43, 44].

Software as a Service (SaaS): Provides a ready-to-use application fully managed by the cloud provider. This model is designed for end users of the application and organizations that wish to make it available to their employees [35, 40, 43, 44].

Figure 3.5 illustrates the differences between these three service models and the self-hosting approach, where the customer is responsible for all components.

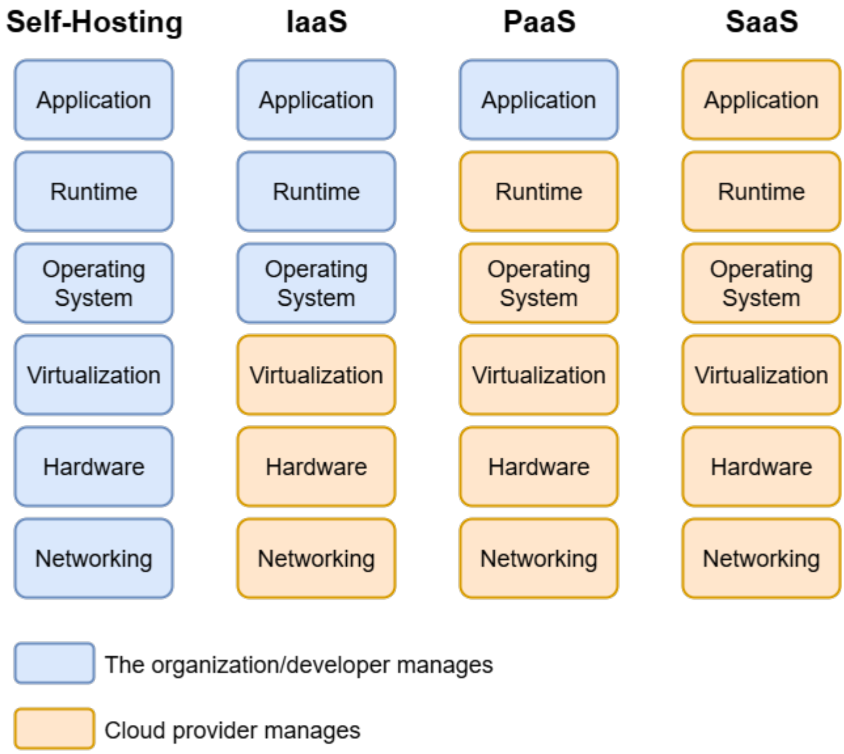

Figure 3.5. Cloud service models

Cloud computing has several advantages over self-hosting. It prevents expensive asset acquisitions and reduces maintenance costs because resources are only paid for when they are actually needed. Furthermore, it allows companies to scale their services as required, since cloud resources can be purchased in practically any quantity and readjusted fast. Cloud providers also have fallback data centers they can resort to in case of failure without affecting the user experience, improving reliability. Finally, by providing on-demand infrastructure, cloud computing speeds up the development and testing of new solutions while decreasing financial risk, promoting innovation [35, 40, 45, 41, 42].

Nevertheless, cloud computing also has some disadvantages. Choosing a cloud-based service means that a third-party organization, possibly a foreign one, now manages sensitive data. This raises security issues, as well as legal considerations related to data protection regulations. Another drawback is low interoperability; once a company chooses a particular cloud provider, changing to another or working with multiple is difficult. In addition, the limited flexibility and customization of cloud computing can inhibit integration with certain systems [40, 45].

Overall, cloud computing is changing the way businesses deliver their software solutions. It is democratizing the impact of IT by giving companies of any size instant access to high-quality computing infrastructure. With this technology, software developers can develop and deploy web applications faster while reducing costs [35, 44, 41].

3.7. Containerization

Containerization is an approach to deploying software where an application, along with all its necessary dependencies (libraries, frameworks, configuration files, etc.), is packaged into a single unit called a container. Containerization is a virtualization technology that is popular in cloud and microservice environments due to its beneficial characteristics [35, 46, 47].

Containers are portable and self-sufficient packages, which ensures they run consistently across different environments. This consistency reduces deployment issues and makes it easier to set up new environments. Additionally, unlike regular VMs, containers virtualize their OS, meaning they only contain the application itself, with no OS overhead. Because of this, containers use less memory and Central Processing Unit (CPU) power, making them more efficient and scalable than VMs [35, 46, 47].

Docker is the leading container platform. It automates and standardizes the deployment of applications inside software containers by providing an additional layer of abstraction to the containerization process. To create a container, Docker uses a Dockerfile, a text-based script of instructions used to create a container image. This immutable image is a lightweight, standalone, executable package that contains everything needed to run an application. When the image is run, it becomes a container, which is an active instance of the image [35, 46, 47].

3.8. Literature Review Conclusion

The literature review presented in this chapter highlighted the main concepts and technologies relevant to this dissertation.

First, an overview of freight transportation, the business domain of the web API to be developed, was provided. This overview was useful to understand the commercial purpose of the web API and its functional requirements.

Then, this literature review covered the concept of web APIs, their specifications, security methods, and popular development frameworks. In the context of this dissertation, web APIs represent the server-side of web applications. Web APIs expose an interface that allows clients to interact with the server's resources. The most popular specifications for web APIs are REST, GraphQL, and RPC. Regarding security, authentication and authorization mechanisms like OAuth 2.0, OIDC, JWTs, and API keys are essential to protect sensitive operations and data. The source code a web API can be simplified and standardized by using a framework intended for this type of software.

After that, two architectural patterns for web APIs were discussed, explaining the advantages and disadvantages of a microservices architecture compared to a monolithic one. The microservice-based architecture has many benefits, especially in large-scale applications, but it also introduces complexity.

Finally, cloud computing and containerization were presented. Cloud computing allows companies to access high-quality infrastructure and services on demand, simplifying the deployment and management of web applications. Containerization is a virtualization technology that improves the portability, consistency, and efficiency of deployed applications.

One key characteristic of this literature review is the lack of studies that contribute with a comprehensive architectural approach for web APIs or web applications. The few documents that do exist tend to focus on specific aspects of web API architecture, such as security or scalability, rather than providing a holistic view. Chapters 4 and 5 intend to address this issue by detailing the design, architecture, and implementation of a web API that follows modern practices described in this literature review.

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CHAPTER 4

Design and Architecture

This chapter details the design and architecture of the web API developed in this dissertation. This process was driven by the theoretical knowledge presented in Chapter 3 and the specific software requirements listed in Section 4.1.

4.1. Requirements

The design and architecture of the web API are guided by a specific list of software requirements. These include functional requirements that establish the system's features, and non-functional requirements that determine the attributes of the system and how it should operate. Every requirement is listed below:

Requirement 1. Provide freight quotes to users by querying external carrier APIs for freight rates (WebCargo for air, Cargofive for sea). To achieve this, the system must expose an endpoint that accepts a payload containing the origin, destination, and other parameters, depending on the transport mode.

Requirement 2. Provide users with their quote search history via a GET request, which contains both the requests they made and the responses they received from the web API. The results must support pagination.

Requirement 3. Allow only users with the administrator role to access information about other users of the web API.

Requirement 4. Expose endpoints for querying supported airports and seaports. The query must have pagination and search term options.

Requirement 5. When a user deletes their account, also delete all associated data from the databases.

Requirement 6. Restrict the functionalities described in Requirements 1, 2, and 3 to authenticated users only.

Requirement 7. In case of a complete failure in one external carrier API integration, the rest of the system must remain operational.

Requirement 8. Support decoupled and automatic scaling of the web APIs's request processing capabilities based on real-time use of specific endpoints.

Requirement 9. Freight rates from external carrier APIs must be cached for 1 day to avoid reaching rate limits.

Requirement 10. When serving concurrent 200 users sending basic GET requests, the 90th percentile response time must be less than 500 milliseconds. Basic GET requests are those that simply retrieve a database record based on its unique identifier.

Requirement 11. Enforce a single public entry point to access the web API's functionality and data.

Requirement 12. Authentication must be done securely via the OAuth 2.0 and OIDC protocols, without storing user credentials in the system's databases.

Requirements 1 to 5 are functional, whereas Requirements 6 to 12 are non-functional. Requirement 1 was explicitly specified by the industry partner Devlop. To expand the scope, others were added as reasonable requirements for a real-world, enterprise web API.

4.2. High-Level Architecture

The high-level architecture focuses on the main components of the system and concisely describes their roles. For the remainder of this document, the names of all major components will be capitalized. Figure 4.1 shows the high-level architecture of the web API.

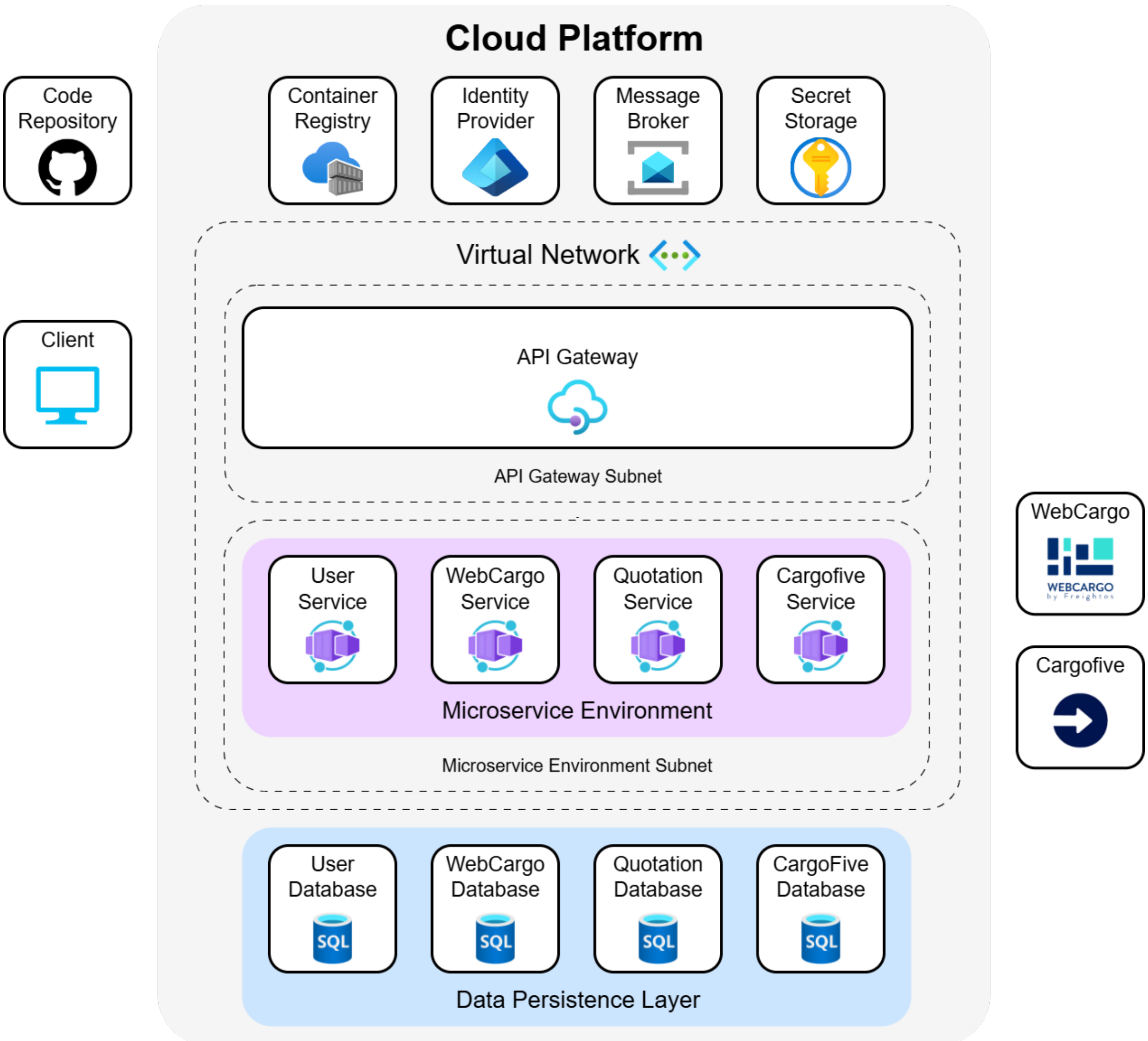

Figure 4.1. High-Level Architecture

4.2.1. Client

The Client is the user-facing application that serves as the primary interface to the system. It is a decoupled frontend from another project, implemented as a Single-Page Application (SPA). Its main responsibilities are to render the User Interface (UI), manage user sessions, and communicate with the API Gateway for data and functionality. For user authentication and account management, the Client directs users to a dedicated page on the Identity Provider, where they can log in, log out, delete their account, etc.

4.2.2. API Gateway

The API Gateway functions as the single entry point for all incoming Client requests, similarly to the pattern described in Subsection 3.5.2. This component routes requests to the appropriate microservice, allowing the Client to interact with the system without needing to know what microservices it contains. The API Gateway also enforces authentication by validating access tokens (JWTs).

4.2.3. Microservice Environment

The Microservice Environment holds the core of the system's business logic, implemented following a microservices architecture described in Subsection 3.5.2. The microservices in this environment are designed around specific business goals, communicating with each other directly through endpoints exposed between them, or indirectly through the Message Broker component. In this web API, each microservice enforces its own authorization policies, restricting access to resources based on roles or more complex business rules. In addition, every microservice runs in a Docker container. There are four microservices in this environment, which are considered major components of the system:

User Service: This service provides endpoints to retrieve user-related information. To do so, it communicates with the Identity Provider. It also communicates with the Identity Provider to be informed about user deletions, which it propagates to the rest of the system through the Message Broker. Even though User Service does not store user data, it still needs an associated database to store data related to the Identity Provider. The purpose of this data is explained in Chapter 5.

Quotation Service: This service orchestrates the core freight quotation business logic. It communicates with WebCargo Service and Cargofive Service to obtain freight rates and uses them to calculate and store freight quotes based on user input received through the API Gateway. Users can fill out a freight quote request and obtain a response with a freight quote, as well as retrieve their quote history. Quotation Service also stores data relevant to the general quotation process, including locations (airports and seaports) and special handling codes. This general data is anonymously accessible through endpoints.

WebCargo Service: This service is responsible for all business logic related to the WebCargo external API, which is used to obtain up-to-date air freight rates. It extracts all relevant information present in the freight rates retrieved from the

WebCargo API and stores them in the corresponding database. Most importantly, it provides air freight rates to Quotation Service when requested.

Cargofive Service: Analogously to the WebCargo Service, this service interacts with the Cargofive external API to fetch current sea freight rates. It extracts all relevant information present in the retrieved freight rates and stores them in its associated database. Its defining role is to supply freight rate data to Quotation Service upon request.

4.2.4. Virtual Network (VNet)

The VNet provides network isolation for the system's components in the cloud platform. The Microservice Environment and the API Gateway reside in the VNet, each in its dedicated subnet. The main objective of these dedicated subnets is to implement network segmentation, enforcing network policies that apply to all inbound and outbound traffic. Specifically, the API Gateway subnet is configured to allow inbound traffic from the Internet, while the Microservice Environment subnet only accepts traffic from within the VNet. Furthermore, components within the VNet can securely access other components (the Message Broker, the Secret Storage, and the Data Persistence Layer) via private endpoints, which integrate them directly into the VNet's address space.

4.2.5. Data Persistence Layer

The Data Persistence Layer manages the persistent storage of the web API's data. This layer may consist of multiple database technologies, as each microservice owns its data and communicates with its corresponding database. Access to this layer is secured through a private endpoint within the VNet.

4.2.6. Identity Provider

The Identity Provider is an external service responsible for all user authentication and account management. It implements the OAuth 2.0 and OIDC protocols to authenticate users and issue JWTs to the Client. By delegating authentication and account management to an instance of a specialized Identity Provider, the system avoids storing user credentials and benefits from enterprise-level security features, such as multifactor authentication.

4.2.7. Message Broker

The Message Broker facilitates asynchronous communication between microservices and employs a publish-subscribe model. This component is useful when one service must send a notification or delegate a task but does not need to know the exact recipients nor receive a direct response. The Message Broker also implements mechanisms for message durability and delivery guarantees in case a microservice subscribes to a topic after messages have already been published. In this web API, the Message Broker is utilized when User Service needs to notify the system that a user has been deleted. In addition, it is used when Cargofive Service needs to synchronize data with Quotation Service. The Message Broker is accessed through a private endpoint within the VNet.

4.2.8. Secret Storage

The Secret Storage is a centralized and secure repository for all application secrets. This contains API keys for external carrier APIs (WebCargo and Cargofive) and the secret value to access the Identity Provider instance as an administrator. The microservices access the Secret Storage at runtime through a private endpoint within the VNet.

4.2.9. WebCargo and Cargofive APIs

The WebCargo and Cargofive APIs are third-party dependencies that provide essential business functionality not built in the system. The system integrates with these APIs to retrieve up-to-date freight rates from many carriers, as explained in Subsection 4.2.3. WebCargo Service and Cargofive Service communicate with the WebCargo and Cargofive APIs respectively, using the API keys supplied by Devlop for authentication. Each of these external APIs has its own documentation and usage policies. Furthermore, the WebCargo API returns responses in XML format, while the Cargofive API uses JSON.

4.2.10. Code Repository

The Code Repository is the version control system that stores the source code of all microservices and Continuous Integration/Continuous Delivery (CI/CD) pipeline workflows. These workflows automate the build and deployment process and are triggered when the source code is updated. These workflows access the Container Registry and the Microservice Environment components through privately stored secrets.

4.2.11. Container Registry

The Container Registry is a private repository for storing and managing the versioned container images for each microservice. During the CI/CD process, new Docker images are built and pushed to the registry. Subsequently, these images are pulled from the registry to be run as Docker containers, where each container is an instance of a particular microservice within the Microservice Environment.

4.3. Runtime Communication

The architecture presented in Section 4.2 defines a set of components. These components must communicate with each other to achieve their objectives. This section explains the web API's runtime communication, which refers to the exchange of data between components that typically occurs while the microservices are running.

4.3.1. Client-Server Communication

The client-server communication includes all requests sent by the Client to a server-side component: either the API Gateway or the Identity Provider. It also includes the API Gateway routing to the correct microservice, since successful Client requests are ultimately handled in the Microservice Environment. Figure 4.2 illustrates these interactions.

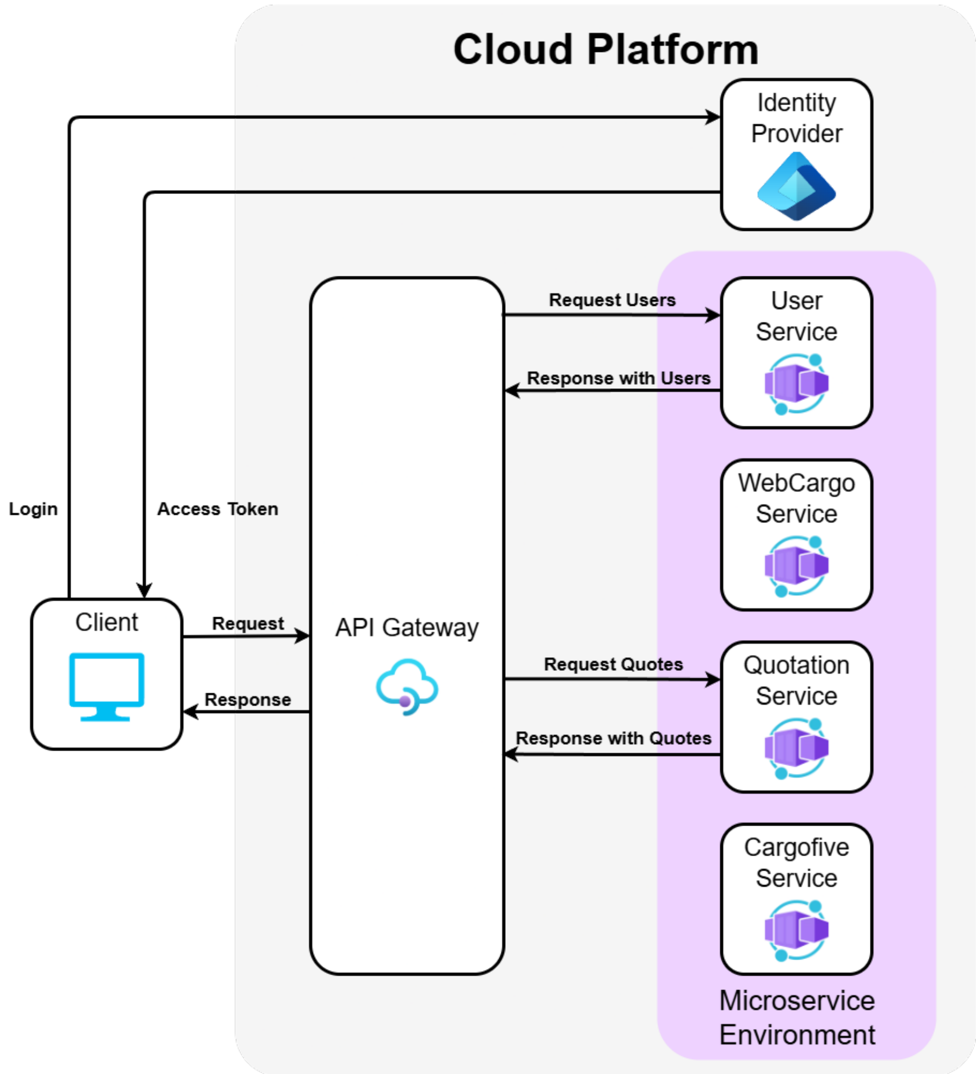

FIGURE 4.2. Client-Server Communication

The Client initiates authentication by redirecting users to the Identity Provider's login page. After a successful login, the Identity Provider redirects the user back to the Client with an authorization code. The Client then exchanges this code for an access token (JWT) by making a request to the Identity Provider's token endpoint, completing the authentication process.

The Client sends requests to the API Gateway to access the web API's resources. If the particular resource requires authentication, the API Gateway first validates the access token included in the request's authorization header. Then, if the token is valid or no authentication is needed, the API Gateway routes the request to the appropriate microservice in the Microservice Environment. The microservice processes the request and sends a response back to the API Gateway, which forwards it to the Client.

4.3.2. Identity Provider Communication

User Service exposes endpoints that allow the Client to get information about users. Since the Identity Provider is responsible for storing user accounts, User Service communicates with it to retrieve user data. This communication is shown in Figure 4.3. Additionally, User Service polls or subscribes to the Identity Provider for user account updates.

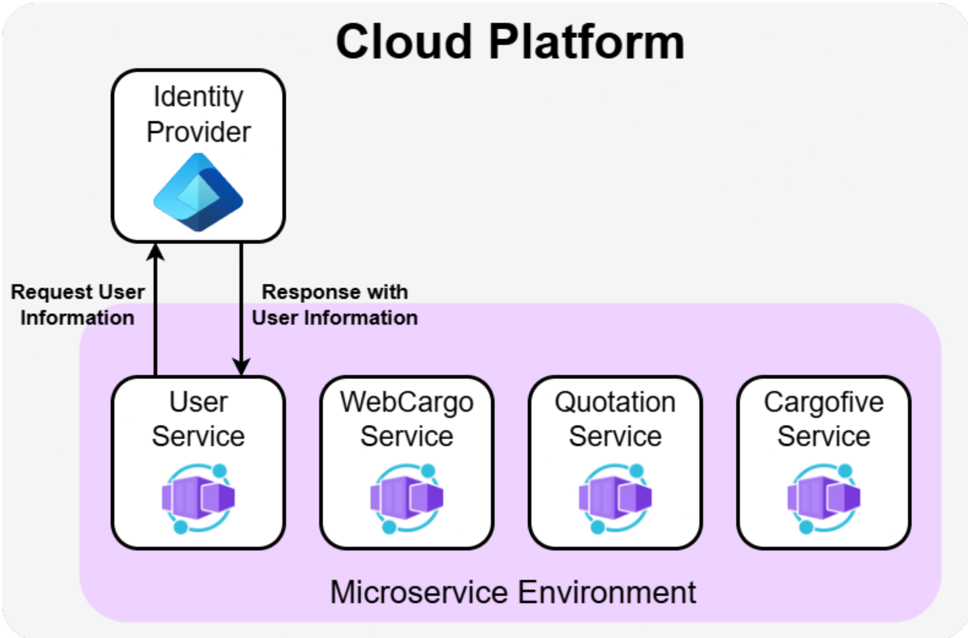

FIGURE 4.3. Identity Provider Communication

4.3.3. Database Communication

Each microservice establishes a connection to its correspondent database and performs the necessary queries to retrieve or modify data. Access to the Data Persistence Layer is secured through a private endpoint within the VNet. Figure 4.4 illustrates the communication between microservices and their databases.

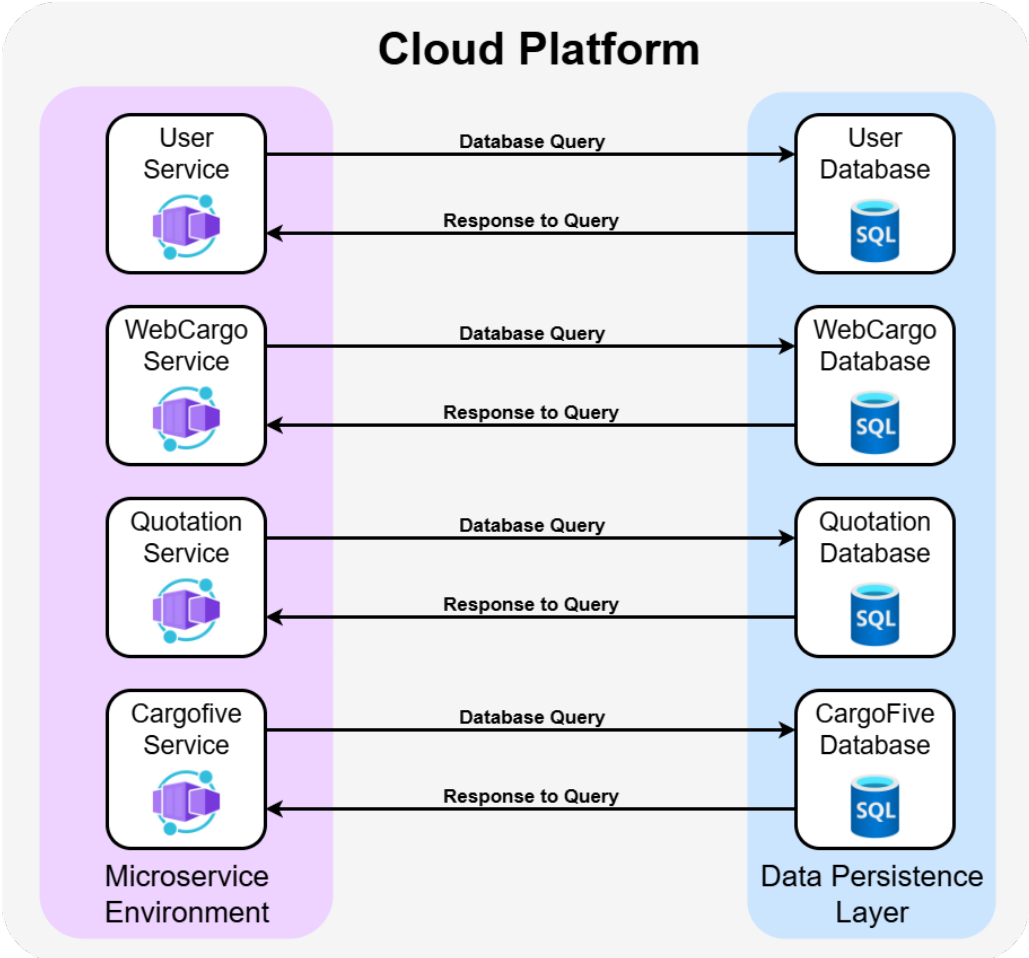

Figure 4.4. Database Communication

4.3.4. Direct Inter-Service Communication

Microservices can communicate with each other directly by making HTTP requests to each other's endpoints. Some of these endpoints may only be reachable to other services, not the Client. This allows for real-time data exchange and coordination between services.

The web API makes use of this type of communication when Quotation Service requires freight rates from WebCargo Service or Cargofive Service, as shown in Figure 4.5.

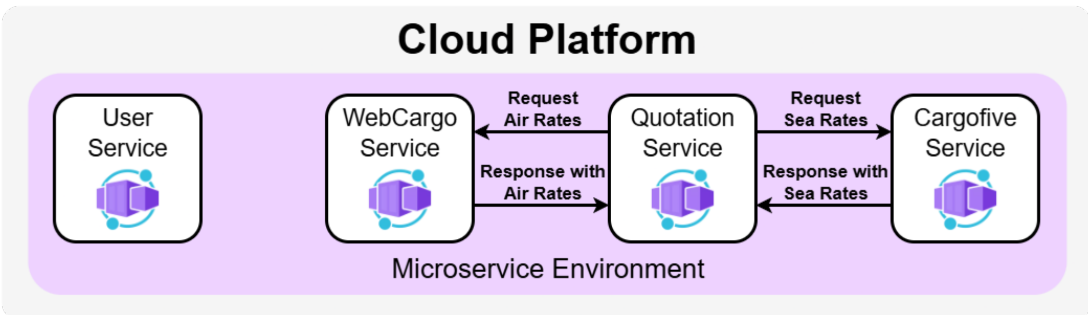

Figure 4.5. Direct Inter-Service Communication

4.3.5. Event-Driven Inter-Service Communication

Event-driven communication is applied in two scenarios using the Message Broker, as explained in Subsection 4.2.7.

The first scenario occurs when a user deletes their account through the Identity Provider.

Firstly, User Service must be informed about the deletion to propagate it to the rest of the system. To achieve this, it can either poll the Identity Provider periodically or subscribe to its user deletion notifications. Once User Service is informed, it publishes a "UserDeleted" event to the Message Broker containing the identifier of the deleted user. Finally, Quotation Service receives this event and deletes the quotation search history of the deleted user from its database. The user deletion event process is shown in Figure 4.6.

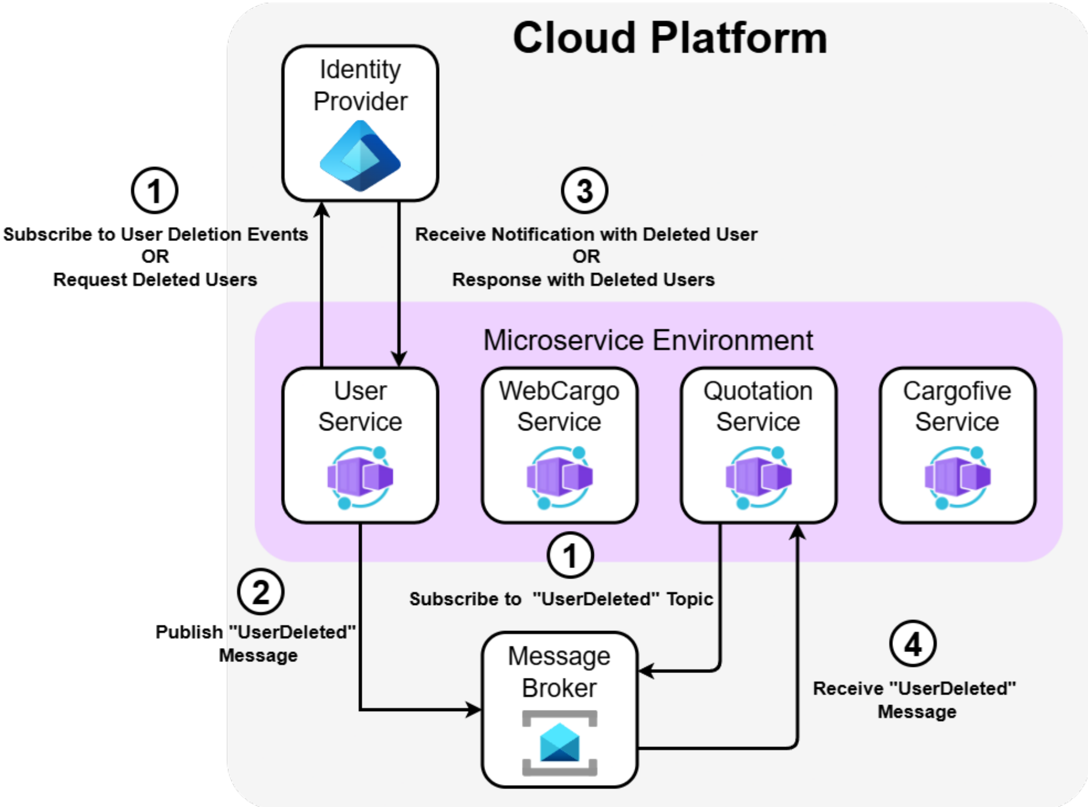

FIGURE 4.6. Event-Driven Inter-Service Communication: User Deleted

The second scenario occurs when Cargofive Service needs to synchronize data with Quotation Service. This synchronization is necessary because the Cargofive API uses its own identifiers for seaports, unlike the WebCargo API, which can identify airports through standardized codes. Cargofive Service fetches the list of supported seaports from the Cargofive API weekly. Cargofive Service publishes a "SeaportsUpdated" event to the Message Broker with the relevant data. Quotation Service is subscribed to this event, so it is notified and updates its database if necessary. This process is shown in Figure 4.7.

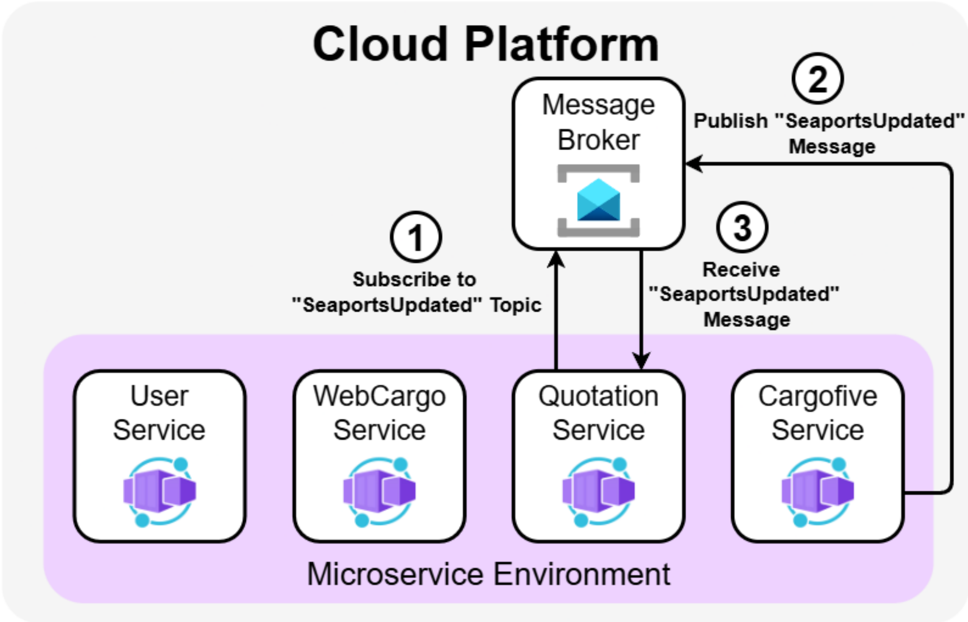

FIGURE 4.7. Event-Driven Inter-Service Communication: Cargofive Synchronization

4.3.6. External Carrier API Communication

WebCargo Service and Cargofive Service communicate with the WebCargo and Cargofive APIs, respectively. The two services use the corresponding API as clients to obtain freight rates by making requests and receiving responses, as shown in Figure 4.8. The API keys required for authentication are retrieved from the Secret Storage at runtime and then stored in memory.

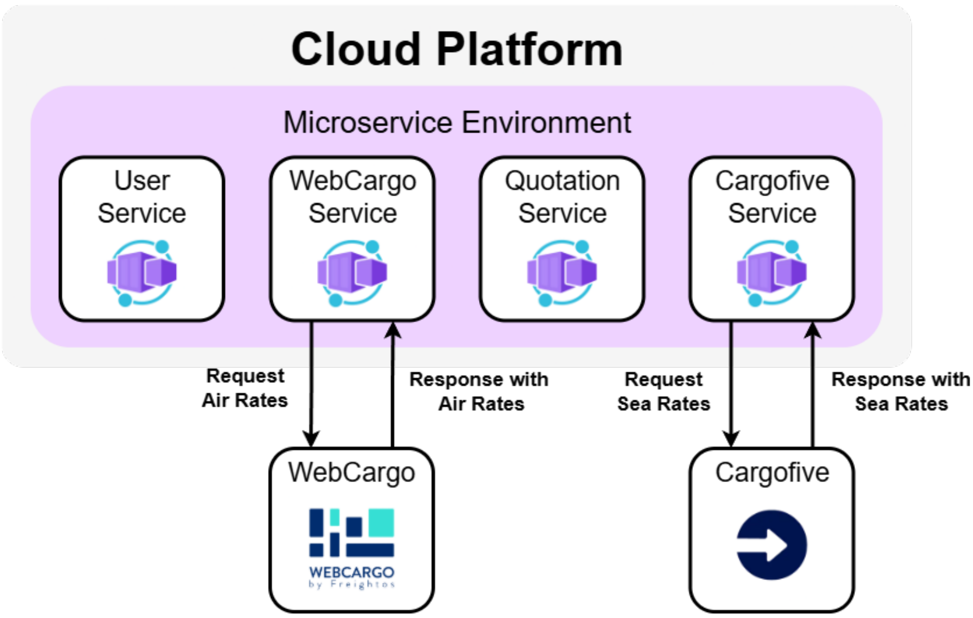

FIGURE 4.8. External Carrier API Communication

4.4. API Specification

The API specification is a document that lays out the endpoints, data schemas, and request-response formats of the web API, providing a clear notion of how to interact with it. Figure 4.9 shows the web API's specification, which adheres to the OpenAPI standard[1]. This document contains all endpoints that the microservices expose to the Client through the API Gateway.

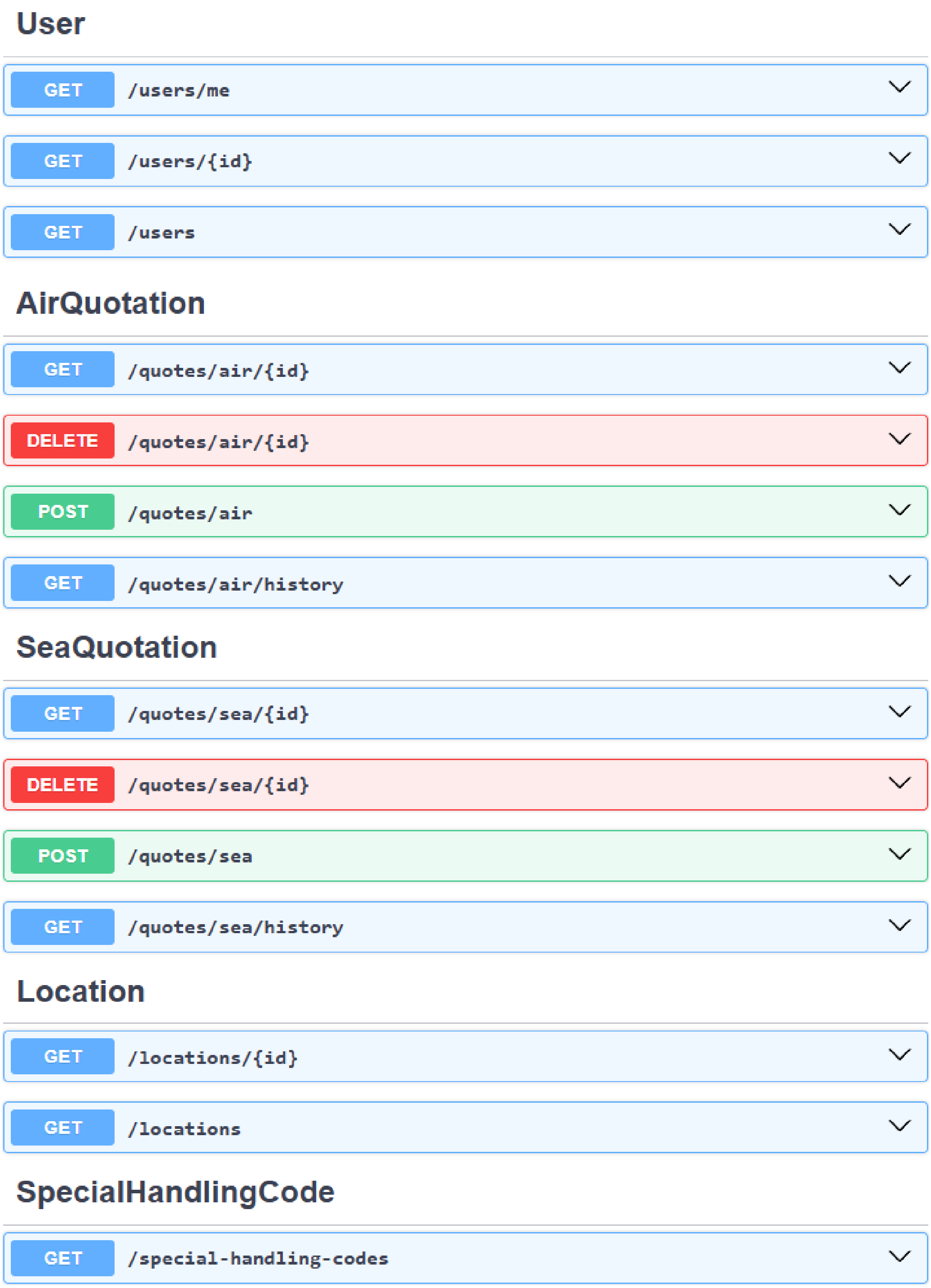

FIGURE 4.9. API Specification

[1]OpenAPI Specification, `https://swagger.io/specification/`, (accessed 31 Aug. 2025)

4.5. Internal Architecture of the Microservices

In the web API, the source code of each microservice adheres to a similar architecture. Figure 4.10 shows the main modules of this architecture and their interactions, where all arrows inside the "Microservice" region represent function calls in the running program. Each module is designed to handle specific types of tasks and responsibilities, promoting code modularity and maintainability. The next subsections explain the purpose of each module.

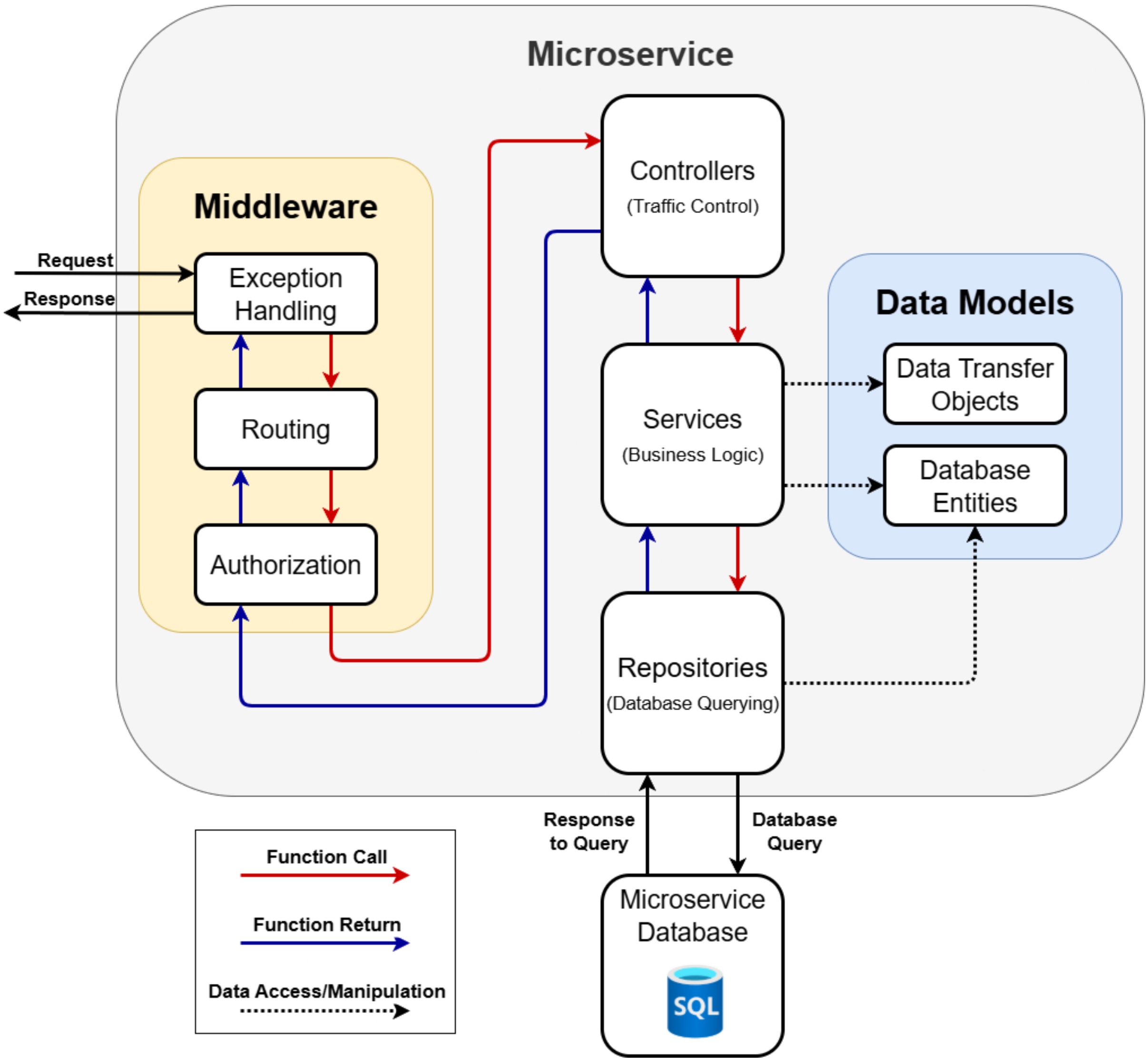

FIGURE 4.10. Internal Architecture of a Microservice

4.5.1. Middleware

The middleware pipeline directly interacts with incoming requests and outgoing responses in a specified order of middleware processes. Each process can inspect or change the request or response. In the web API being designed, three middleware processes are applied in this exact order:

Exception Handling: This process is invoked at the beginning of the request pipeline. If an unhandled error occurs during the processing of a request, it catches the error and generates a response with a fitting error code and message.

Routing: This process is responsible for matching incoming requests to the appropriate endpoint based on the request's specified destination. The destination of the request depends on its Uniform Resource Locator (URL) and HTTP method.

Authorization: This process checks whether the authenticated user has the necessary permissions to access the requested resource. If the user lacks the required permissions, it blocks the request and generates a response with a "403 Forbidden" status code. For endpoints that allow anonymous access, this process has no effect. Authentication and authorization requirements are defined in the controller modules.

4.5.2. Data Models

Data models represent business data structures. In the web API's source code, they correspond to objects that are designed for data encapsulation and contain no business logic. There are two types of data models:

Data Transfer Objects (DTOs): These objects hold business data and may contain validation or transformation logic. Microservice components use DTOs for data interchange in many API interactions, including those with the Client, other microservices, and the external carrier APIs.

Database Entities: These data models represent database tables and are used to map the microservice's business data to the the correspondent database schema. An instance of a database entity is equivalent to a row in the database table it represents. Database entities allow the database schema to be programmatically defined in the microservice's source code.

4.5.3. Controllers

Controllers are responsible for handling requests routed by the middleware. Each controller defines one or more endpoints corresponding to a specific resource (location, user, freight quote, etc.) or functionality of the microservice. These modules control traffic by specifying each endpoint's authentication and authorization requirements, as well as their expected input and output parameters. Controllers interact with the necessary Service modules to fulfill the request and initiate a response with relevant data to the Client.

4.5.4. Services

Service modules execute the core business logic of the microservice and coordinate interactions between other modules. They use DTOs to exchange data with external APIs, the Client, and other microservices. These modules can create database entity instances directly to then store them in the database by interacting with repository modules. Service modules also interact with repository modules to retrieve, modify, or delete database records.

4.5.5. Repositories

Repositories provide functions for database access and manipulation. They act as an abstraction layer between the service modules and the database, holding the logic required to interact with the microservice's database. Repositories use database entity instances to perform CRUD operations on behalf of service modules. Furthermore, repository modules are agnostic to specific database technologies.

4.6. Deployment

The web API's microservices are deployed to the cloud platform through a CI/CD pipeline. This pipeline automates the build, test, and deployment processes, ensuring that the relevant microservice instances running in the cloud are promptly updated. The CI/CD pipeline is triggered whenever a change that is pushed to the master branch of the Code Repository affects the microservices' source code. Figure 4.11 illustrates the two main steps of the deployment process.

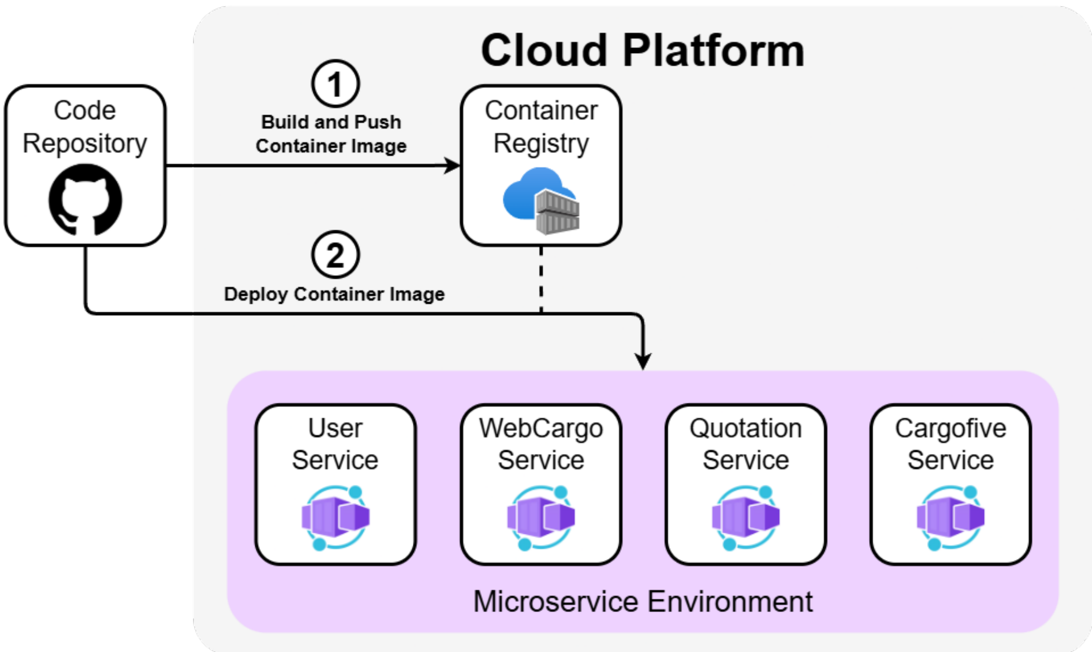

FIGURE 4.11. Deployment to the Cloud Platform

In the first stage, the source code is compiled with a production-ready configuration and built into a container image, which is then pushed to the Container Registry. In the second stage, the container image is deployed to the cloud platform's container orchestration service (the Microservice Environment), where it is run in a scalable and supervised environment. Both of these stages involve authenticating with the relevant cloud platform components using secrets stored in the Code Repository.

4.7. Technology Stack

Although the web API's architecture described throughout Chapter 4 is intentionally agnostic to a specific technology stack, particular technologies must be chosen for the implementation stage in Chapter 5.

The selected cloud platform is Microsoft Azure[2], which provides a wide range of PaaS services that facilitate the creation and management of the web APIs's components. Table 4.1 links each cloud platform component mentioned in Section 4.2 to the corresponding Azure service type.

Web API Component	**Azure Service**
API Gateway	API Management
Microservice Environment	Container Apps Environment
VNet	Virtual Network
Data Persistence Layer	SQL Server
Identity Provider	Microsoft Entra ID
Message Broker	Service Bus
Secret Storage	Key Vault
Container Registry	Container Registry

Table 4.1. Azure Service of each Cloud Platform Component

Every microservice in the Microservice Environment is built with the ASP.NET Core 8.0 framework, using C# as the programming language. This framework was chosen for its performance, extensive documentation, and integration with Azure services. Finally, the web API follows the REST architectural style for simplicity and standardization.

[2]Microsoft Azure, `https://azure.microsoft.com/`, (accessed 31 Aug. 2025)

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CHAPTER 5

Implementation

This chapter describes and demonstrates the implementation of the web API designed in Chapter 4. It enumerates the development tools, showcases the functionality of all microservices, explains the configuration of the cloud platform components, and describes the deployment process.

5.1. Development Environment

During development, JetBrains Rider[1] Integrated Development Environment (IDE) was used as the main tool for writing, testing, and debugging the microservices' source code. This IDE provides a vast set of features, including code completion, refactoring tools, and integrated debugging support. These features significantly increase developer productivity.

Docker Desktop[2] was installed to test the Docker containers and register them in the Container Registry.

All cloud platform components were configured and managed in the Azure Portal, which offers an intuitive graphical interface.

Postman[3] was utilized to manually validate the web API's endpoints during development by acting as the Client component.

The complete source code for the API's microservices and their respective deployment workflows are available in a public GitHub repository[4].

5.2. Microservices Implementation

5.2.1. Project Structure

There are five projects in the .NET solution, one for each microservice and a shared project. Each microservice project contains its own implementation of the architecture described in Section 4.5. The shared project contains common code that can be useful to multiple microservices, such as constant values and utility functions. Figure 5.1 shows the project structure of the solution, with Quotation Service being chosen as the example.

[1]JetBrains Rider, `https://www.jetbrains.com/rider/`, (accessed 31 Aug. 2025)
[2]Docker Desktop, `https://www.docker.com/products/docker-desktop/`, (accessed 31 Aug. 2025)
[3]Postman, `https://www.postman.com/`, (accessed 31 Aug. 2025)
[4]`https://github.com/RafaelSantos777/FreightQuotationWebAPI`

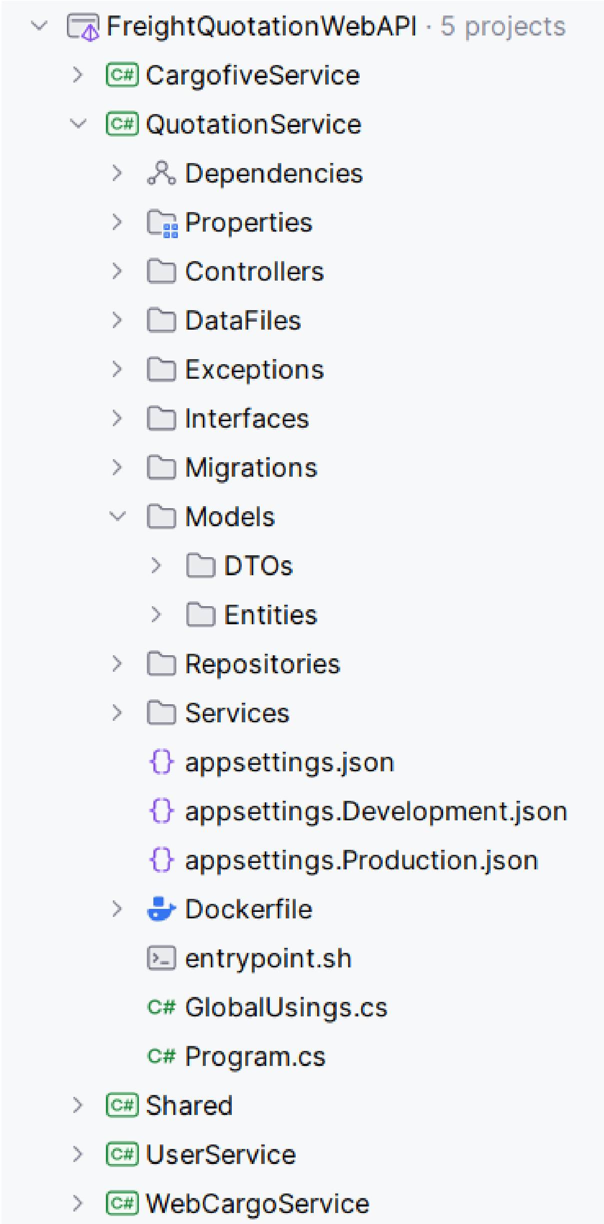


FIGURE 5.1. Project Structure

Besides the microservice components described in Section 4.5, each microservice also contains other important directories and files, including:

Dependencies: This directory contains all NuGet package dependencies required by the microservice.

DataFiles: This directory consists of miscellaneous data files. Quotation Service reads files in this directory to store initial data for locations and special handling codes, which are loaded into the database when the microservice starts for the first time.

Exceptions: This directory contains custom exception classes that represent specific error conditions in the microservice.

Interfaces: This directory contains interface definitions for Service and Repository modules. These interfaces define the contracts that implementing classes must adhere to, promoting loose coupling and easier testing.

Migrations: This directory holds the database migration files generated by .NET Entity Framework Core. These files define the changes to be applied to the database schema over time. When the database definition in the source code changes, a new migration file is created to represent the change. The database migration is applied before the microservice starts.

appsettings.json: This file contains configuration settings for the microservice, such as database connection strings and information related to the cloud platform components. There are also environment-specific versions of this file ("appsettings.Development.json" and "appsettings.Production.json") that specify additional settings when the microservice is running in a specific environment. These files do not contain secret values.

Dockerfile: This file defines the instructions to build a Docker image for the microservice. It specifies the base image, copies the source code, builds the project, and defines the entry point for running the microservice in a container.

entrypoint.sh: This script is executed when the microservice container starts. The microservice container has two distinct behaviors based on the parameters passed to this script. If the first parameter is "migrate", the script applies any pending database migrations and then exits. Otherwise, the script runs the microservice normally by executing the code defined in Program.cs.

Program.cs: This C# file is responsible for configuring the web server, the middleware pipeline, and starting the web API.

5.2.2. Freight Rates and Quotes Obtainment

When user makes a quote request to the web API, it is routed to Quotation Service, which orchestrates the process by interacting with WebCargo Service and Cargofive Service.

Through configuration files, Quotation Service knows the addresses of WebCargo Service and Cargofive Service, which depend on whether the services are running in a local development environment or in an Azure production environment. Figures 5.2 and 5.3 show the addresses used in each environment. The addresses in a production environment are mapped to the full domain names of the services in the VNet through Domain Name System (DNS) records.

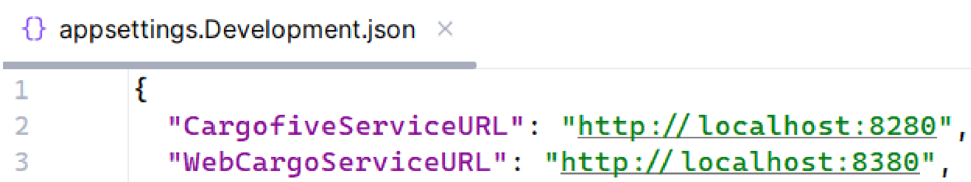


FIGURE 5.2. Service Addresses (Development Environment)

```
appsettings.Production.json
{
    "CargofiveServiceURL": "http://cargofive-service",
    "WebCargoServiceURL": "http://webcargo-service",
```

FIGURE 5.3. Service Addresses (Production Environment)

In this subsection, the process of obtaining an air freight quote is described. The process for sea freight quotes is analogous, with the only significant difference being that Cargofive Service is used instead of WebCargo Service.

When Quotation Service receives an air quote request from an end user, it is transformed into a DTO corresponding to a C# object shown in Figure 5.4. If the DTO is valid, Quotation Service sends a direct request to a WebCargo Service. This request comprises all the essential query parameters to search for air freight rates from the WebCargo API: the International Air Transport Association (IATA) codes of the origin and the destination airports. Quotation Service stores locations in its database, so it can retrieve the IATA codes based on the location identifiers received in the air quote request. Quotation Service and WebCargo Service have an equivalent definition of the request DTO, shown in Figure 5.5. Figures 5.4, 5.5, and upcoming figures in this chapter contain blurred elements to hide irrelevant details.

```
namespace QuotationService.Models.DTOs.Internal;
public record AirQuoteRequestDTO {
    long OriginAirportId
    long DestinationAirportId
    double LengthCentimeters
    double WidthCentimeters
    double HeightCentimeters
    double WeightKilograms
    string CurrencyCode
    string? SpecialHandlingCode
```

FIGURE 5.4. Air Quote Request DTO

```
namespace WebCargoService.Models.DTOs.Internal;

public record RateRequestDTO {

    string OriginAirportIATACode
    string DestinationAirportIATACode
```

FIGURE 5.5. Air Rate Request DTO

When WebCargo Service receives the freight rate request, it checks if a valid cache entry exists for the given origin and destination. If it does, the cached freight rates are simply returned to Quotation Service as a list of DTOs shown in Figure 5.6.

If no valid cache entry exists, a request is made to the WebCargo API. Once the response is received, its body containing the freight rates is deserialized into a list of DTOs with a structure similar to the WebCargo API's response body. Then, the retrieved freight rates are stored in the cache and sent to Quotation Service as previously described.

```
namespace WebCargoService.Models.DTOs.Internal;

public record RateDTO {

    long UniqueCode
    string Airline
    string OriginAirportIATACode
    string DestinationAirportIATACode
    decimal VolumetricFactorMetric
    string ProductName
    string CurrencyCode
    DateOnly ValidFrom
    DateOnly? ValidTo
    string SpecialHandlingCodeString
    List<RateSurchargeDTO> Surcharges
    decimal MinimumBreakpointCost
    List<RateBreakpointDTO> Breakpoints
```

FIGURE 5.6. Air Rate DTO

Finally, Quotation Service works with the received freight rates to calculate freight quotes based on the user's input. The freight quote response is stored in the database and returned to the user as a DTO shown in Figure 5.7.

```
namespace QuotationService.Models.DTOs.Internal;

public record AirQuoteResponseDTO {

    long Id
    AirQuoteRequestDetailedDTO AirQuoteRequestDetailed
    List<AirQuoteDTO> AirQuotes
```

FIGURE 5.7. Air Quote Response DTO

The functionality described in this subsection can be tested in Postman. Figure 5.8 shows an example air quote request, where "baseUrl" is the URL of the API Gateway. Figure 5.9 shows a part of the corresponding response.

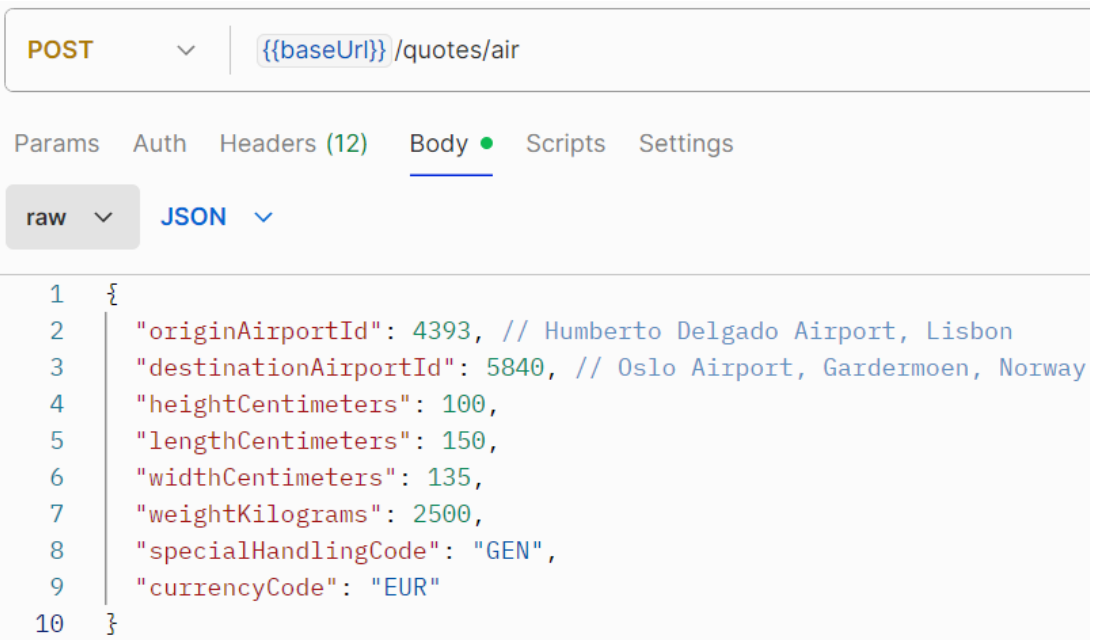


Figure 5.8. Air Quote Request in Postman

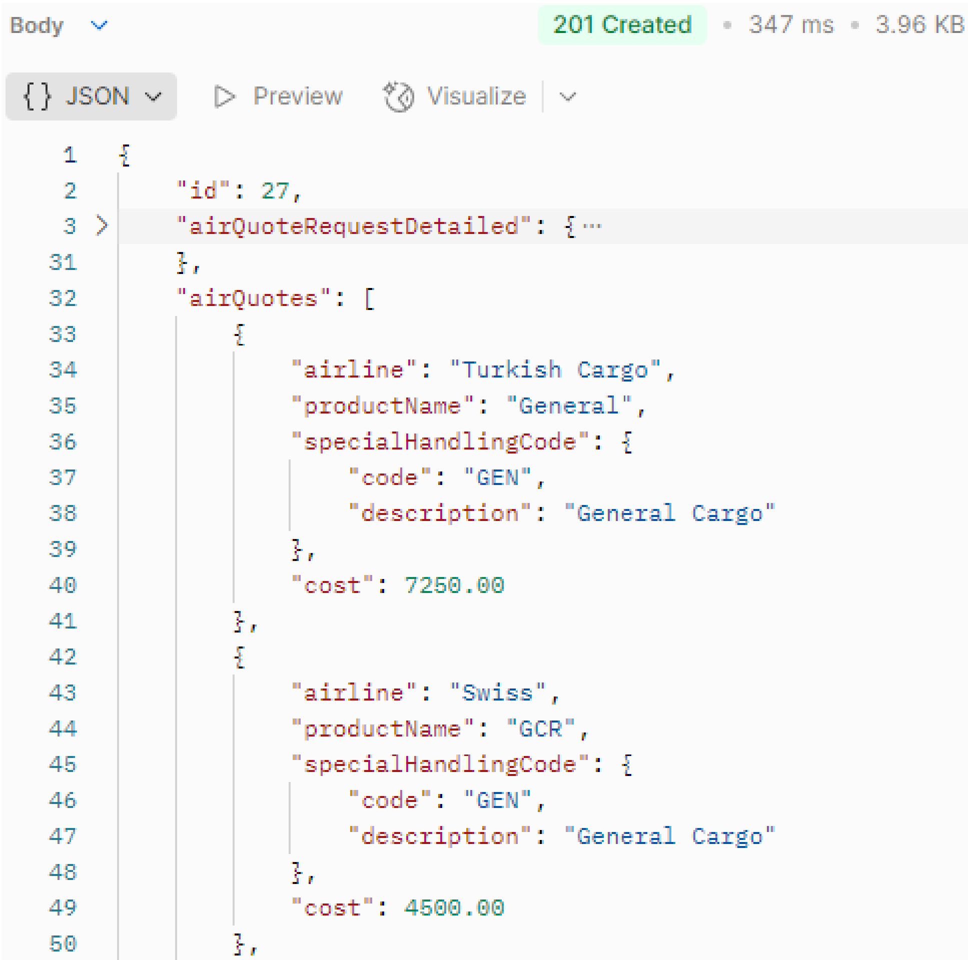


Figure 5.9. Air Quote Response in Postman

5.2.3. Freight Rates Cache

External carrier APIs impose rate limits on the number of requests that can be made within a specific time frame. To avoid exceeding these limits, freight rates obtained from the WebCargo and Cargofive APIs are cached for 1 day. The caching mechanism is implemented in WebCargo Service and Cargofive Service, respectively.

Each cache entry is based on a unique combination of request parameters that define what freight rates will be returned by the external carrier API. For both APIs, a combination of the origin and the destination locations is sufficient to uniquely identify a cache entry. When a request for freight rates is received, the service first checks if a valid cache entry exists. If it does, the cached freight rates are returned. If not, a request is made to the external carrier API, and the retrieved freight rates are stored in the cache.

The main purpose of the caching mechanism is to reduce the number of requests to the external carrier APIs. Because of this, the databases of WebCargo Service and Cargofive Service store not only the rate history, but also the cached data, for simplicity. However, this implementation has some drawbacks, such as increased cached lookup times and potential database load. In future work, a dedicated caching alternative would be useful for its increased performance and built-in cache expiration mechanisms.

5.2.4. Quote History

Whenever Quotation Service processes a freight quote request, it stores the request and response data in its database. This allows users to retrieve their quotation history through a dedicated endpoint.

The returned history is ordered from newest to oldest and paginated to limit the number of results in a single response. Pagination parameters are specified in the request query string. The parameter "page" indicates the page number, while "limit" indicates the number of results per page. If these parameters are not specified, default values are used (1 for page and 100 for limit).

Figure 5.10 shows an example request to the quote history endpoint in Postman. Figure 5.11 shows the corresponding response, which was collapsed for visibility.

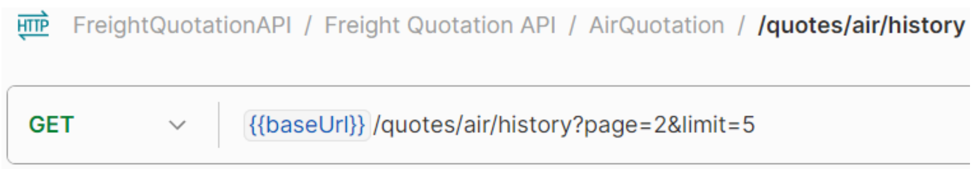


Figure 5.10. Quote History Request in Postman

FIGURE 5.11. Quote History Response in Postman

5.2.5. Location Search

Quotation Service exposes an endpoint that allows users to search for locations by name. This functionality is useful when users need to find the identifier of a location to use in a freight quote request.

The location search endpoint accepts a query parameter for the location name and another for the location type. Furthermore, it supports pagination, similarly to the one described in Subsection 5.2.4. The endpoint returns a list of matching locations with their identifiers and other information.

Figure 5.12 shows an example request to the endpoint in Postman for airport locations whose name contains "barce". Figure 5.13 shows the resulting response.

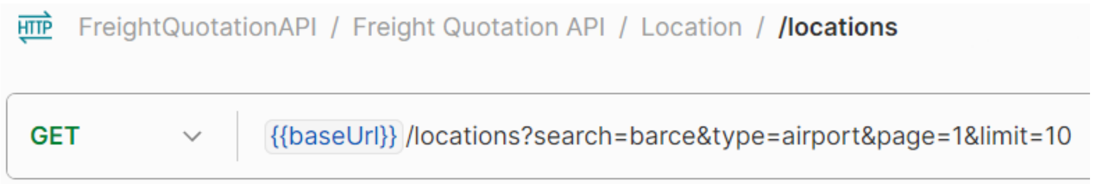


FIGURE 5.12. Location Search Request in Postman

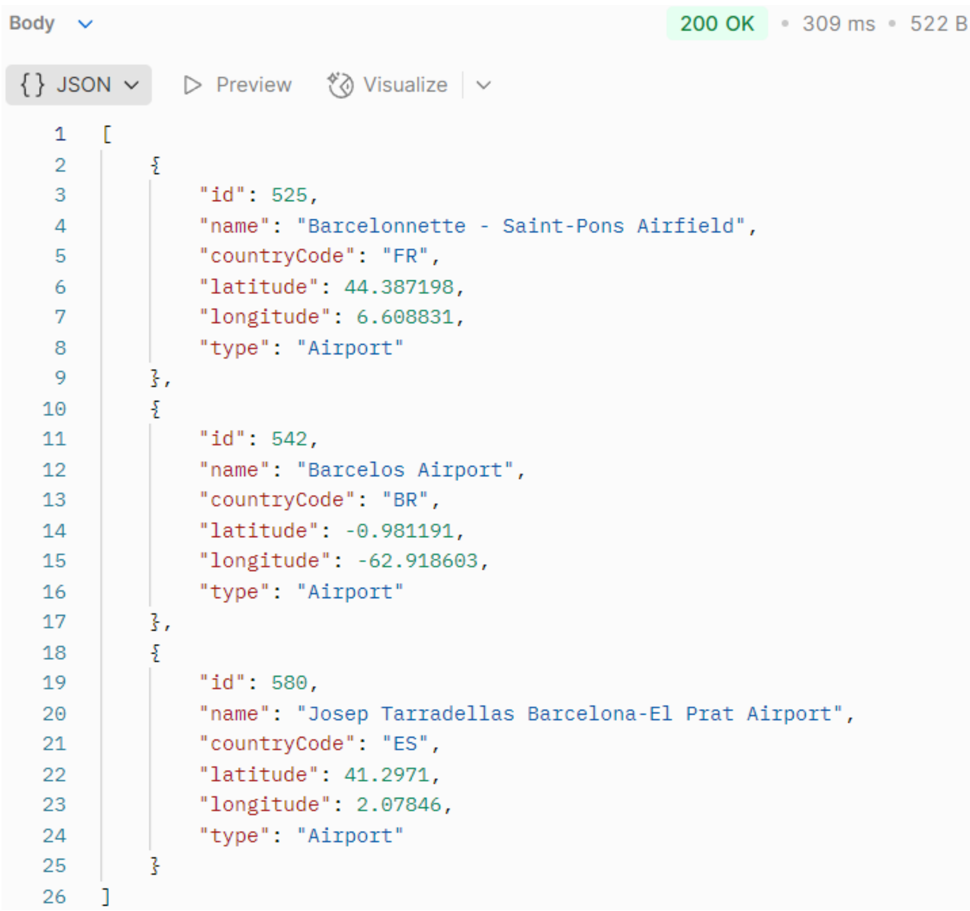


FIGURE 5.13. Location Search Response in Postman

5.2.6. Role-Based Access Control (RBAC)

The microservices rely on the authentication verification performed by the API Gateway. Therefore, they do not need to validate access tokens themselves. Still, they must enforce authorization policies to restrict access to resources based on user roles or more complex business rules.

Only users with the "Administrator" role can access the endpoint to search for other users in the system. User roles can be found in the "roles" claim of the access token (JWT). User roles can be assigned manually through the Azure portal. Alternatively, User Service can assign roles by calling the appropriate Graph API[5] endpoint, which is used to interact with Microsoft's cloud resources.

Figure 5.14 shows a search request in Postman for users whose name contains "mar". Figure 5.15 shows the "403 Forbidden" response received when the request is made with a JWT of a user without the "Administrator" role. Conversely, Figure 5.16 shows the successful response received when the request is made with a JWT of an administrator.

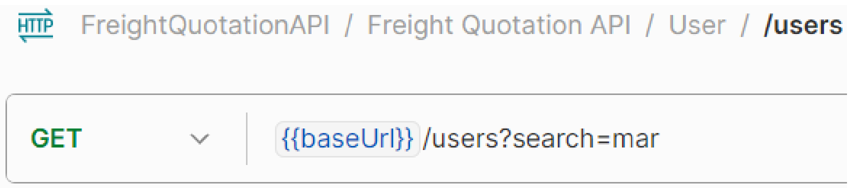


FIGURE 5.14. User Search Request in Postman

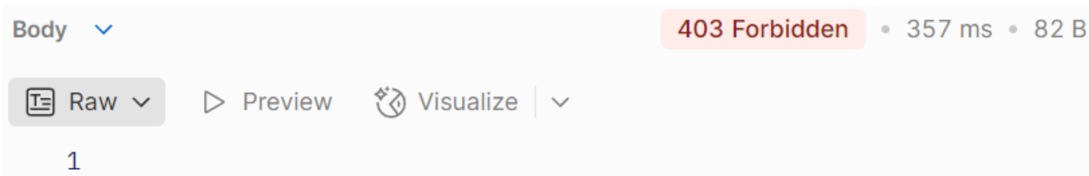


FIGURE 5.15. User Search Response in Postman (Access Forbidden)

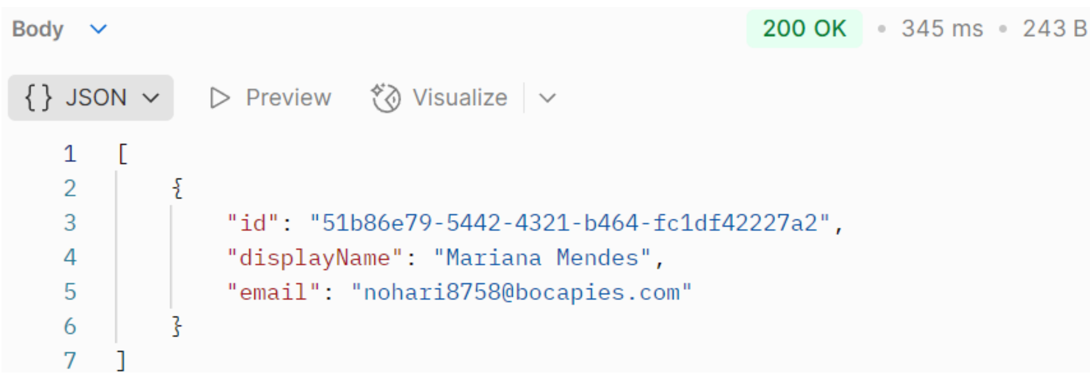


FIGURE 5.16. User Search Response in Postman (Success)

[5] Microsoft Learn, "Use the Microsoft Graph API", `https://learn.microsoft.com/en-us/graph/use-the-api`, (accessed 15 Sep. 2025)

5.2.7. User Data Deletion

When a user is deleted, all their associated data is also deleted from the web API's databases. Since Entra ID is the Identity Provider, it is responsible for managing user accounts. Therefore, User Service must be informed about user account deletions by communicating with Entra ID. In Subsection 4.3.5, two possible approaches to get this information were mentioned: subscribing to the Identity Provider's user deletion notifications, or polling the Identity Provider periodically. Entra ID supports both approaches through the Microsoft Graph API.

The first approach involves subscribing to Microsoft Graph API's change notifications for user deletions. This requires setting up a webhook endpoint in User Service to receive notifications, which Entra ID communicates with. However, the Graph API only supports this method for workforce tenants, which are intended for employees of an organization. The implemented web API is intended for general customer users and thus utilizes a different tenant type. Therefore, this event-driven approach is not feasible for the web API.

The second approach involves polling the Microsoft Graph API. Indiscriminate polling would be inefficient, as it would involve returning all users and checking for deletions. Instead, User Service uses delta queries[6] to retrieve only the changes that occurred since the last query. This is achieved by storing a delta link provided by the Graph API after each query in the User Service's database. The delta link is then used in subsequent queries to fetch only the changes since the last query. User Service polls the Graph API every 15 minutes.

When User Service retrieves at least one deleted user through polling, it sends a batch of messages to a Service Bus (Message Broker) topic called "user_deleted". Each message contains the identifier of a deleted user. Any microservice may subscribe to this topic. In particular, Quotation Service has a subscription to this topic and processes each message by deleting the quote history of the corresponding user from its database.

5.3. Cloud Components Configuration

5.3.1. API Gateway Configuration

An Azure API Management instance is used to route incoming requests to the appropriate microservice, thus acting as the API Gateway. A single API is added to the API Management instance by importing the definition from the OpenAPI specification file mentioned in Section 4.4. This API is named "Freight Quotation API". Since there is only one registered API, the term "API Gateway" will be used to refer to both the API Management instance and the Freight Quotation API.

The API Gateway has a "Settings" tab, shown in Figure 5.17, where general configurations are made. Secure HTTP access is enforced by allowing only Hypertext Transfer Protocol Secure (HTTPS) requests. Furthermore, the base public URL is defined

[6] Microsoft Learn, "Use delta query to track changes in Microsoft Graph data", `https://learn.microsoft.com/en-us/graph/delta-query-overview`, (accessed 15 Sep. 2025)

("https://quotationapigateway.azure-api.net/api"), which clients must use to access the web API.

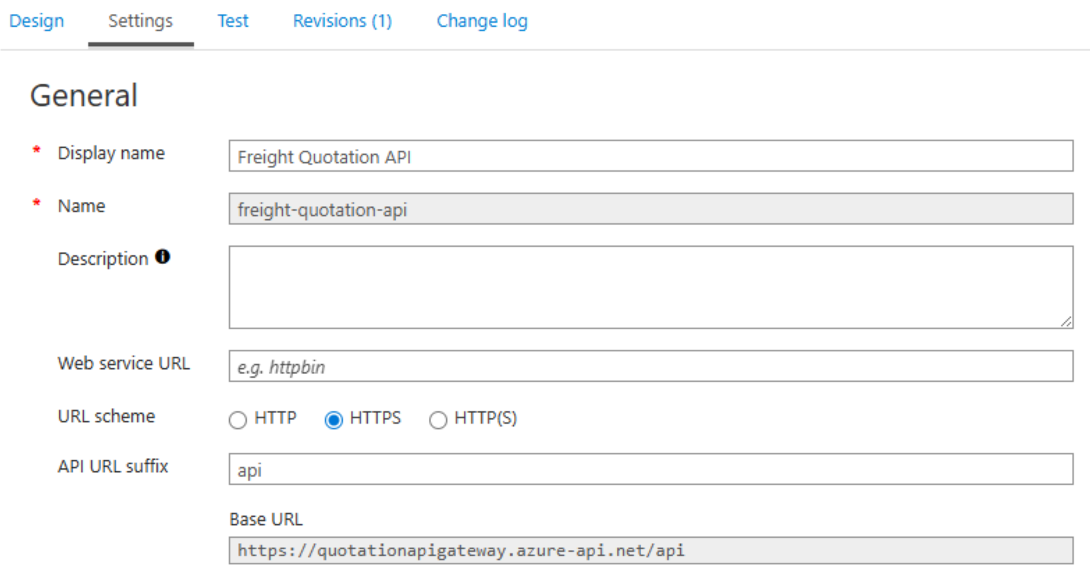


FIGURE 5.17. API Gateway Settings

Unlike the microservice components, the API Gateway accepts communication from the public internet, as it resides in a subnet that allows such traffic. The microservices, which reside in a different subnet, rely on the API Gateway to interact with the Client. Because of this, each microservice is added as a separate backend service to the API Gateway, as shown in Figure 5.18. The "Backend name" is used as a simple alias to identify the backend service. The "Run URL" is the internal URL of the microservice in the VNet.

Backend name	Description	Type	Runtime URL
quotation-service		Custom URL	https://quotation-service.greenground-aff007cf.spaincentral.azurecontainerapps.io
user-service		Custom URL	https://user-service.greenground-aff007cf.spaincentral.azurecontainerapps.io

FIGURE 5.18. API Gateway Backends

The API Gateway's behavior is defined in the "Design" tab. In this tab, an XML configuration file defines multiple policies that are applied to incoming requests or outgoing responses. Considering the roles of the API Gateway mentioned in Subsection 4.2.2, the policies can be split into three parts: Cross-Origin Resource Sharing (CORS), authentication, and routing.

CORS policies are applied to all incoming requests to allow cross-origin requests from the Client. Since the Client application does not have a fixed domain name, the CORS policy allows requests from any origin and accepts any HTTP method. However, if the Client had a fixed domain name, the CORS policy would be more restrictive. The CORS policy is shown in Figure 5.19.

```xml
<cors>
    <allowed-origins>
        <!--Allow any origin-->
        <origin>*</origin>
    </allowed-origins>
    <allowed-methods>
        <!--Allow any HTTP method-->
        <method>*</method>
    </allowed-methods>
</cors>
```

FIGURE 5.19. API Gateway CORS Policy

The next step is to enforce authentication by validating the access token (JWT) included in the "Authorization" header of incoming requests. The API Gateway uses the OpenID Connect metadata document of the Identity Provider to validate the token's signature and claims. If the token is invalid or missing, the request is rejected with a "401 Unauthorized" response. Figure 5.20 displays the authentication policy configuration with explanatory comments.

```xml
<choose>
    <!--If accessing "/locations" or "/special-handling-codes" endpoints, skip authentication check-->
    <when condition="@(new [] { "/api/locations", "/api/special-handling-codes" }
    .Any(path => context.Request.OriginalUrl.Path.StartsWith(path)))" />
    <!--If accessing other endpoints, enforce authentication-->
    <otherwise>
        <!--JWT must be speficied in the "Authorization" header of the request-->
        <validate-jwt header-name="Authorization" failed-validation-httpcode="401">
            <openid-config url="https://freightquotation.ciamlogin.com/e2b3262c-0ae0-456d-8c49-6cbe7422af1
            <audiences>
                <!--"83b002e0-b385-4b11-8a7b-5dbf91bf18a4" is the identifier of the server-side web API-->
                <!--Used to verify if the JWT's intended use is for the web API-->
                <audience>83b002e0-b385-4b11-8a7b-5dbf91bf18a4</audience>
            </audiences>
        </validate-jwt>
    </otherwise>
</choose>
```

FIGURE 5.20. API Gateway Authentication Policy

Finally, the API Gateway routes incoming requests to the appropriate microservice based on the request's destination. The routing policy is shown in Figure 5.21. The policy uses the backend identifier of each backend service defined in Figure 5.18 to identify the target microservice.

```xml
<choose>
    <!--If accessing "/locations", "/special-handling-codes", or
    "/quotes" endpoints, route to Quotation Service-->
    <when condition="@(new [] { "/api/locations", "/api/special-handling-codes", "/api/quotes" }
    .Any(path => context.Request.OriginalUrl.Path.StartsWith(path)))">
        <set-backend-service backend-id="quotation-service" />
    </when>
    <!--If accessing "/users" endpoints, route to User Service-->
    <when condition="@(new [] { "/api/users" }.Any(path => context.Request.OriginalUrl.Path.StartsWith(path)))">
        <set-backend-service backend-id="user-service" />
    </when>
</choose>
```

FIGURE 5.21. API Gateway Routing Policy

5.3.2. Microservice Environment Configuration

The Azure Container Apps Environment hosts all microservices as Azure Container Apps. In addition, there is one Container App Job for each microservice, which is used to apply database migrations when a new deployment occurs. The Container Apps Environment resides within a dedicated subnet ("ContainerEnvironmentSubnet") in the VNet to ensure secure communication. This subnet adheres to the default Azure subnet policies, which only allow traffic from other components within the VNet, or private endpoints. Figure 5.22 shows the overall configuration of the Container Apps Environment.

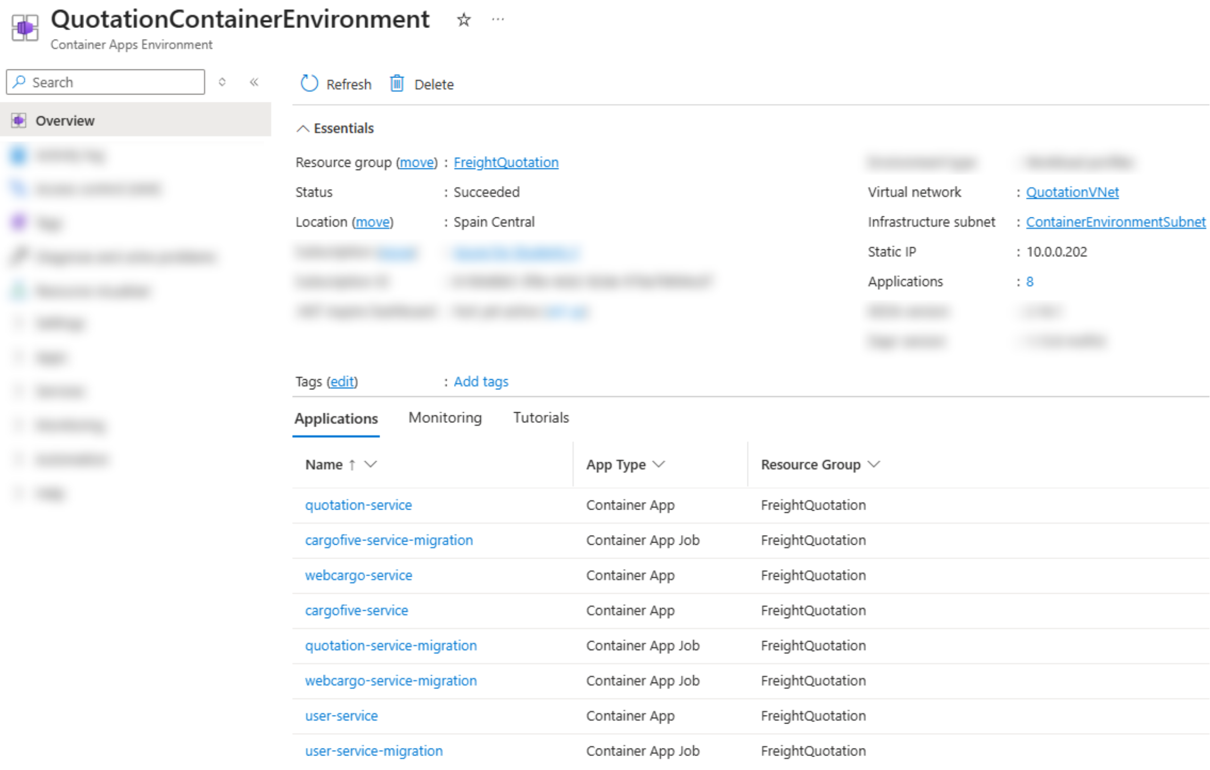


Figure 5.22. Container Apps Environment Configuration

Each microservice is deployed as a separate Container App. Each Container App runs a specific Docker image version stored in the Container Registry. When the CI/CD pipeline deploys a new version of a microservice, it updates the Container App to use the new Docker image, creating a revision of the Container App. Microservices run in Docker containers of that image. Each microservice instance has 0.5 general-purpose Virtual Central Processing Units (vCPUs) and 1 Gibibyte (GiB) of memory allocated.

Another valuable feature is the ability to set scaling rules for each microservice, which can be based on HTTP traffic, CPU usage, or memory usage. Specifically, every Container App is configured to scale between 1 and 10 instances, based on the average number of concurrent HTTP requests being processed per instance. If this number exceeds 50, the Container App will automatically scale up to deal with the increased load. Conversely, if the average workload remains lower for 5 minutes, the Container App will scale down to conserve resources. Figure 5.23 shows the scaling configuration.

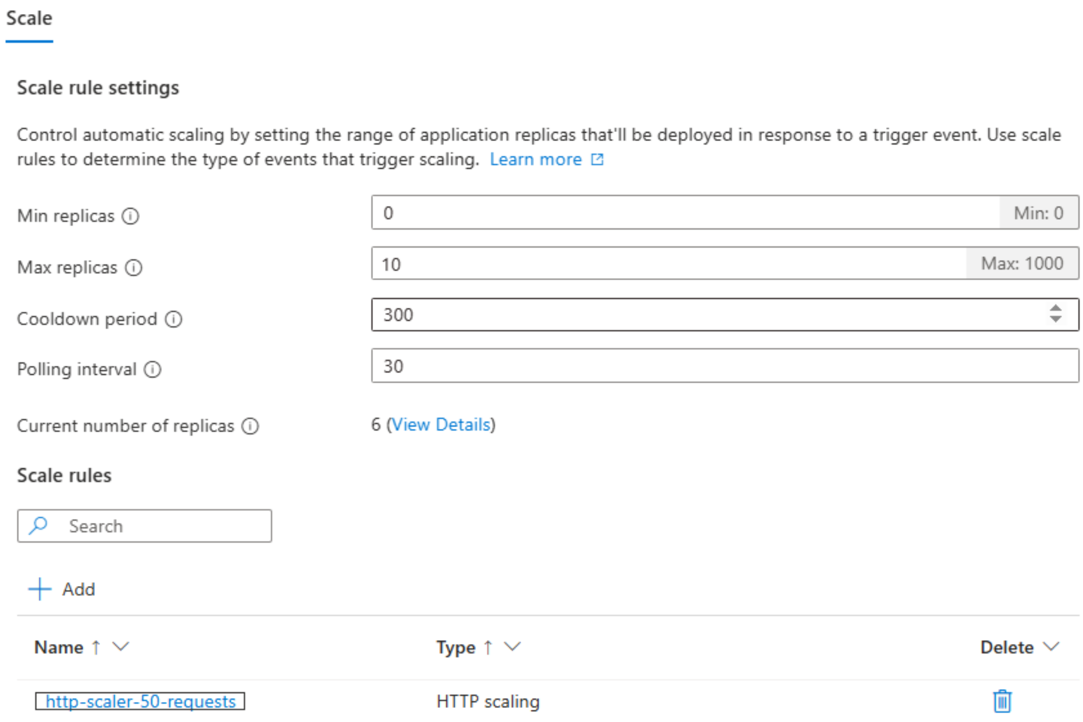


FIGURE 5.23. Container App Scaling Rules

5.3.3. Data Persistence Layer Configuration

An Azure SQL Server instance hosts the databases of all microservices. Each microservice has its own SQL database. Public access to the SQL Server is disabled, so the server can only be accessed from within the VNet through a private endpoint.

Every microservice connects to its database through passwordless authentication, allowing Container Apps to authenticate without storing confidential connection strings. Instead, a generic connection string that depends only on the name of the target database is enough. To achieve this, each Container App is assigned a managed identity, which is then granted the "db_datareader" and "db_datawriter" roles in the target database. Figure 5.24 shows the active managed identity of WebCargo Service's Container App, which is similar for all other microservices. Figure 5.25 demonstrates the subsequent step, where a Structured Query Language (SQL) query executed in the Azure Portal to assign the necessary database roles.

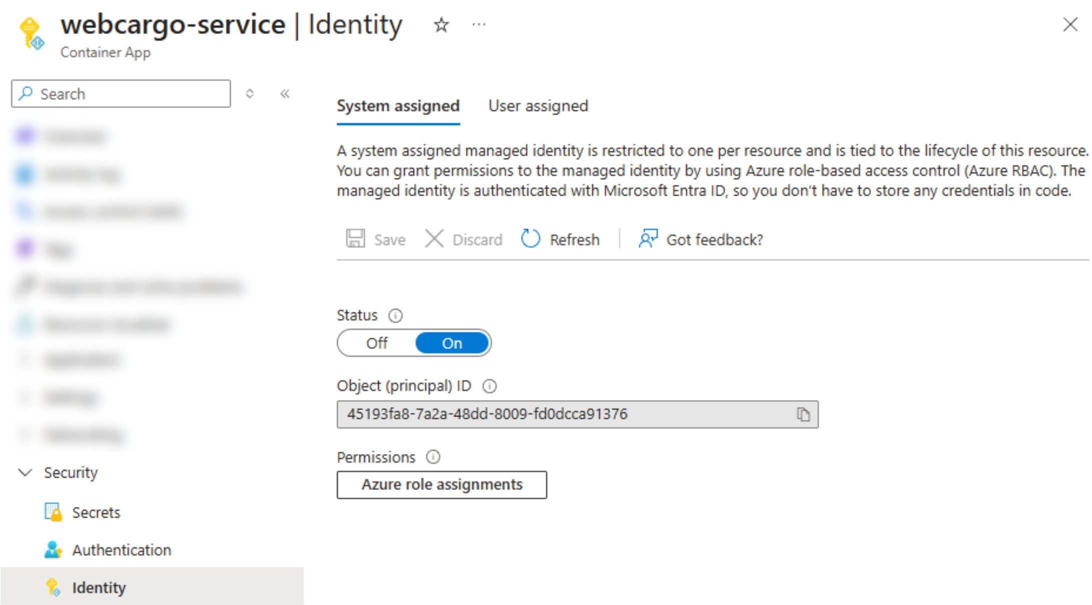


FIGURE 5.24. Container App's Managed Identity

Run | Cancel query | Save query | Export data as | Show only Editor

```sql
-- Add Container App as database user
-- The managed identity has a unique name, so "webcargo-service" may be used instead of the Object ID
CREATE USER [webcargo-service] FROM EXTERNAL PROVIDER;
-- Grant read permissions
ALTER ROLE db_datareader ADD MEMBER [webcargo-service];
-- Grant write permissions
ALTER ROLE db_datawriter ADD MEMBER [webcargo-service];
```

FIGURE 5.25. Database Roles Assignment

Different databases may have differing computation power and storage capacity, depending on the microservice's needs. All databases have 16 Gigabytes (GBs) of storage, to save costs. In terms of computation power, Quotation Service's database has 2 general-purpose vCPUs, while the other microservices' databases have the default 1 vCPU. This disparity is due to the fact that this database will be used in performance testing. Figure 5.26 shows the basic configuration properties of the Quotation Service's database, which is similar to all others, barring the number of vCPUs.

Compute + storage

Service tier	General Purpose
Compute tier	Serverless
vCores	2 vCores
Max storage	16 GB

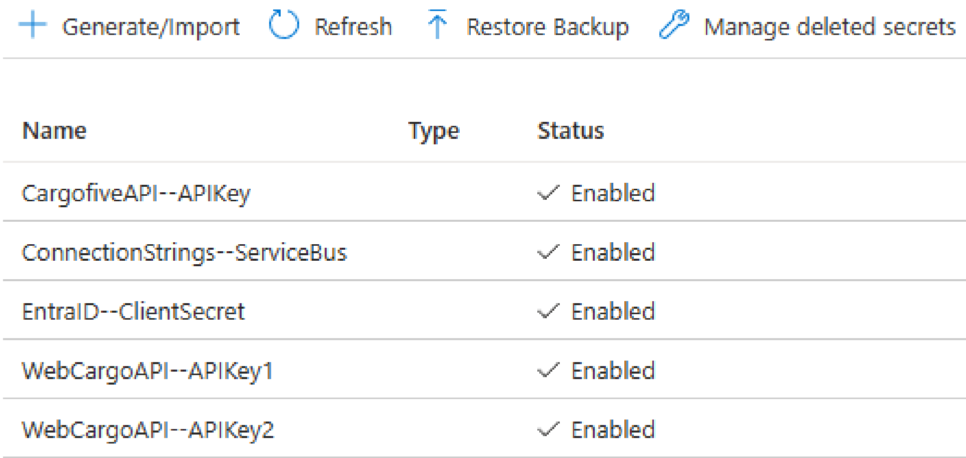
Networking

Public access	Disabled
Firewall rules	1 firewall rule
Virtual networks	0 virtual network service endpoints
Private access	1 private endpoint connections

FIGURE 5.26. SQL Databases Base Configuration

5.3.4. Secret Storage Configuration

For security reasons, the source code of every microservice does not contain any secret values. Instead, Azure Key Vault is used to securely store confidential information for production environments, which is made available to the microservices through a private endpoint. The Key Vault stores the API keys to authenticate with external carrier APIs, the Service Bus connection string, and the secret to access Entra ID's resources. Figure 5.27 enumerates the names of all secrets.



+ Generate/Import   Refresh   Restore Backup   Manage deleted secrets

Name	Type	Status
CargofiveAPI--APIKey		✓ Enabled
ConnectionStrings--ServiceBus		✓ Enabled
EntraID--ClientSecret		✓ Enabled
WebCargoAPI--APIKey1		✓ Enabled
WebCargoAPI--APIKey2		✓ Enabled

FIGURE 5.27. Key Vault Secrets

5.4. CI/CD Pipeline Configuration

The Code Repository, which is hosted on GitHub, includes a directory named ".github" containing all CI/CD pipeline configuration files in the "workflows" subdirectory. Each workflow file is associated with a specific microservice. This directory also contains Shell script files in the "scripts" subdirectory that are used as part of the workflows. Figure 5.28 presents the structure of the ".github" directory.

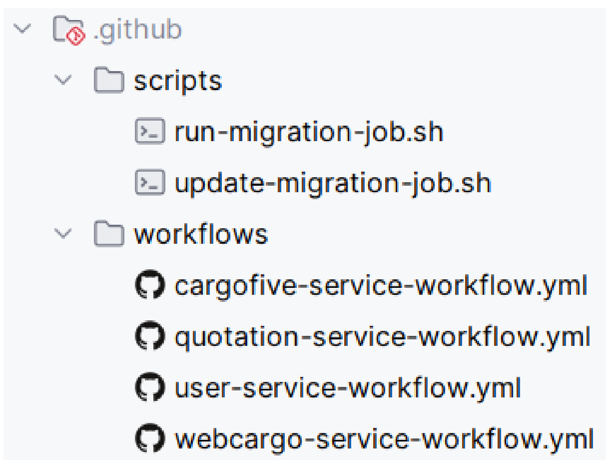


FIGURE 5.28. Github Scripts and Workflows

The workflow file related to Quotation Service will be explained, as an example. The workflows of the other microservices follow equivalent steps.

The beginning of the workflow file defines its name, what conditions trigger its execution, and the environment variables it uses. This particular workflow is triggered when a change that affects either the "QuotationService" or "Shared" root directories is pushed to the master branch. The environment variables include Azure-related values and the name of the root folder of the microservice. Figure 5.29 shows this part of the workflow file.

```yaml
name: Deploy to Azure Container Apps

on:
  workflow_dispatch:
  push:
    branches: [ master ]
    paths:
      - 'QuotationService/**'
      - 'Shared/**'

env:
  CONTAINER_REGISTRY: quotationcontainerregistry-haggcjhshrgxgbgw
  CONTAINER_APP_NAME: quotation-service
  RESOURCE_GROUP: FreightQuotation
  GITHUB_ROOT_FOLDER: QuotationService
```

FIGURE 5.29. Workflow Header

The latest version of Ubuntu is set as the OS of the workflow runner. The first two steps of the workflow are preparatory and do not interact with Azure yet. The first step checks out the source code of the repository, making it available to the workflow runner. The second step sets up Docker functionality. Figure 5.30 shows these steps.

```yaml
jobs:
  build-and-deploy:
    runs-on: ubuntu-latest

    steps:
      - name: Checkout
        uses: actions/checkout@v4

      - name: Set up Docker Buildx
        uses: docker/setup-buildx-action@v3
```

FIGURE 5.30. Workflow Preparation Steps

The objectives of the subsequent two steps are to build and push the new Docker image of the microservice to the Container Registry. The first step logs into the Container Registry using the "docker/login-action" action. This step uses Azure credentials stored in the repository's secrets to authenticate. The second step builds the Docker image according to the Dockerfile present in the directory of the microservice. Then, the workflow runner tags the Docker image with the current commit hash and pushes it to the Container Registry. Figure 5.31 shows these steps.

```yaml
- name: Log in to Container Registry
  uses: docker/login-action@v3
  with:
    registry: ${{env.CONTAINER_REGISTRY}}.azurecr.io
    username: ${{secrets.CONTAINER_REGISTRY_USERNAME}}
    password: ${{secrets.CONTAINER_REGISTRY_PASSWORD}}

- name: Build and push container image to Container Registry
  uses: docker/build-push-action@v6
  with:
    push: true
    tags: ${{env.CONTAINER_REGISTRY}}.azurecr.io/${{env.CONTAINER_APP_NAME}}:${{github.sha}}
    file: ${{env.GITHUB_ROOT_FOLDER}}/Dockerfile
```

FIGURE 5.31. Workflow Docker Build and Push Steps

The next step logs into the Azure account of the web API's resources, which is a prerequisite for the upcoming steps. To authenticate, it uses credentials stored in the Github repository's secrets. Figure 5.32 illustrates this step.

```yaml
- name: Azure Login
  uses: azure/login@v2
  with:
    creds: ${{ secrets.AZURE_CREDENTIALS }}
```

FIGURE 5.32. Workflow Azure Login Step

Once the workflow runner logs into the Azure account, it executes the Shell script named "update-migration-job.sh". This script updates the Container App Job of the microservice to use the new Docker image. This is essential to ensure that the database migration is applied using the latest version of the microservice. Figure 5.33 shows this step.

```yaml
- name: Update Container App Job for migration
  run: ./.github/scripts/update-migration-job.sh
  shell: bash
  env:
    GITHUB_SHA: ${{ github.sha }}
```

FIGURE 5.33. Workflow Migration Job Update Step

The following step executes the Shell script named "run-migration-job.sh". This script starts a new instance of the Container App Job, which applies any pending database migrations to the microservice's associated database. The script then waits for the job to complete successfully before proceeding by periodically checking the execution status. Figure 5.34 shows this step.

```yaml
- name: Run and await migration job
  run: ./.github/scripts/run-migration-job.sh
  shell: bash
  env:
    GITHUB_SHA: ${{ github.sha }}
```

FIGURE 5.34. Workflow Migration Job Execution Step

The last step deploys the Docker image that was pushed to the Container Registry to the Container App associated with the microservice. This effectively updates the running instance of the microservice to the latest version. Figure 5.35 shows this step.

```yaml
- name: Deploy to Container Apps
  uses: azure/container-apps-deploy-action@v1
  with:
    imageToDeploy:
      ${{env.CONTAINER_REGISTRY}}.azurecr.io/${{env.CONTAINER_APP_NAME}}:${{github.sha}}
    resourceGroup: ${{env.RESOURCE_GROUP}}
    containerAppName: ${{env.CONTAINER_APP_NAME}}
```

FIGURE 5.35. Workflow Container App Deployment Step

CHAPTER 6

Evaluation

This chapter analyses the quality of the web API implemented in Chapter 5 in terms of reliability and performance. It also offers the necessary information to estimate the cost of the proposed solution in a real-world scenario. Afterwards, the extent to which the web API satisfies the requirements enumerated in Chapter 4.1 is evaluated.

6.1. Testing Strategy

Unit tests and integration tests are important to ensure the quality of the microservices' source code by automatically verifying their correctness. In the implemented web API, unit tests aim to verify individual microservice components in isolation. On the other hand, integration tests focus on the communication with other microservices, cloud components, or external APIs. Furthermore, testing can be added as a step of the CI/CD pipeline to ensure that changes do not introduce bugs.

However, due to time constraints, the implementation of automated tests was not feasible. Therefore, the testing strategy for the web API relied solely on manual testing. Manual testing was performed using Postman, as demonstrated in Section 5.2. Postman was used to test all endpoints of the web API, including various scenarios that encompassed valid requests, invalid requests, and edge cases. In addition, database records were inspected directly in the Azure Portal to verify that data was being stored as intended.

6.2. Cost Analysis

6.2.1. Cost Analysis Context

Hosting software components on a cloud platform incurs costs. During the development of the web API, free Azure subscriptions with limited budgets were used.

Cloud platforms offer multiple pricing tiers for their cloud services. Pricing tiers focused on development and testing were selected to minimize costs while still providing the necessary features. However, these pricing tiers are not suitable for enterprise production environments, as they have lower limits in terms of performance, scalability, and availability.

Determining concrete monetary values for the cost of hosting the web API is beyond the scope of this dissertation. The goal of the cost analysis is to provide the necessary parameters to estimate the cost of hosting and running the web API in a real-world production environment.

Each cloud platform has distinct pricing models for its services. This section comtemplates three major cloud platforms: Microsoft Azure, Amazon Web Services (AWS)[1], and Google Cloud Platform (GCP)[2]. To simplify, the cost analysis focuses on the most expensive components of the web API. The most expensive components are the API Gateway, the Microservice Environment, and the Data Persistence Layer. Together, they contribute to over 90% of the total cost. This conclusion was reached by examining two main sources: the official pricing documentation for each cloud provider, and the expenditure data from the development phase of the web API.

Table 6.1 summarizes the mapping of web API components to their respective cloud platform services considered for the cost analysis.

Web API Component	**Azure**	**AWS**	**GCP**
API Gateway	API Management	API Gateway	API Gateway
Microservice Environment	Container Apps Environment	Elastic Container Service (ECS)	Cloud Run
Data Persistence Layer	SQL Server	Relational Database Service (RDS) for SQL Server	Cloud SQL with SQL Server

TABLE 6.1. Cloud Platform Service Mapping

6.2.2. Cost Analysis Parameters

The total cost of hosting the web API depends on various parameters, so it is difficult to estimate the cost accurately. Still, the parameters were selected based on the requirements defined in Section 4.1, the results of the performance test in Subsection 6.3.3, and mid-tier pricing plans on the cloud platforms.

Table 6.2 lists all relevant parameters to predict the cost of hosting the web API in the three cloud platforms, along with the rationale behind their values.

[1]Amazon Web Services, `https://aws.amazon.com/`, (accessed 21 Sep. 2025)
[2]Google Cloud Platform, `https://cloud.google.com/`, (accessed 21 Sep. 2025)

Table 6.2: Cost Analysis Parameters

Parameter	Value	Rationale
API Requests (Monthly)	100 Million	Represents 38.6 user requests per second, on average. This value considers the performance test described in Section 6.3, where the web API dealt with 400 requests per second. However, that value is intended to represent a surge in traffic, and does not take into account quotation requests, which are much more complex. Therefore, a much lower value was chosen.
Data Egress (Monthly)	500 GB	Considering value of the "API Requests (Monthly)" parameter, this amounts to an average of 5 Kilobyte (KB) per request response. The size of the responses delivered to users varies heavily, ranging from less than 1 KB, to more than 100 KB for some quote history requests. 5 KB represents a typical quote request response size.
Virtual Network Integration	Yes	The API Gateway must integrate with the VNet, as implemented in the web API. Therefore, VNet integration costs are considered.
Number of Microservices	4	As implemented in the web API.
Microservice CPU (Average)	2 vCPUs	This value assumes each microservice has 4 active instances with 0.5 vCPUs, on average. The processing power of vCPUs may vary between cloud providers, even if they are all part of a general-purpose tier.
Microservice Memory (Average)	4 GiB	This value assumes that, on average, each microservice has 4 instances with 1 GiB of memory running.
Number of Databases	3	User Service's database has extremely low resource requirements. Therefore, only Quotation Service, WebCargo Service, and Cargofive Service's databases were considered.
Database CPU (Static)	4 vCPUs	It is difficult to predict the necessary CPU resources for the databases. Quotation requests involve more resource-intensive queries than the ones used in the performance test, so more than 2 vCPUs were selected. The value of this parameter is also associated with mid-tier options in cloud provider offerings. For easier comparison between cloud providers, the database CPU allocation is static, as opposed to being dynamically adjusted based on load.

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Parameter	Value	Rationale
Database Memory (Static)	16 GiB	This value is in line with cloud provider options offering 4 vCPUs.
Database Storage (Static)	128 GB	The database storage requirements are hard to predict without real usage data. This value coincides with mid-tier options in cloud provider offerings.
Payment Commitment Length	1 Year	For lower costs and easier comparison between cloud providers.
Deployment Region	Paris, France	Cheaper than most other European regions and supports most offerings.
User Traffic Origin	Europe	Applies to all requests, to simplify analysis.

6.3. Performance Evaluation

6.3.1. Performance Test Scenario

A performance evaluation was performed to analyze the responsiveness of the web API under the conditions specified by Requirement 10. To do so, a test scenario was designed and executed with the goal of testing the base performance of the system.

The test scenario consists of simulating 200 concurrent users sending GET requests to the "locations/{id}" endpoint. This involves 200 users sending requests simultaneously to the web API, waiting for a response, and then immediately sending another request once a response is received. This process lasts 3 minutes, with a previous warm-up period of 2 minutes. The warm-up period is important to allow the necessary microservice replicas to be created and initialized before real measurements are considered. The location identifier used for all requests is "1234", which corresponds to an airport location stored in Quotation Service's database. Neither the API Gateway nor Quotation Service have any caching mechanism for endpoint requests, so that every request is processed from scratch.

To satisfy Requirement 10, the 90th percentile of response times must be under 500 milliseconds. This means that at least 90% of all requests must receive a response in less than 500 milliseconds. Considering that the scenario involves 200 concurrent users, the web API must be able to handle at least 400 requests of this type per second, on average. Equation 1 shows how this value is calculated.

$$\text{Requests (per second)} = \frac{\text{Concurrent users}}{\text{Response time (seconds)}} \tag{1}$$

6.3.2. Performance Test Setup and Configuration

The Azure Portal provides a service called "Azure Load Testing" that allows the creation and execution of performance test scenarios. This service was used to set up and run the performance test scenario described in Subsection 6.3.1.

The performance test is an Azure "URL-based test" where a specific public endpoint of the web API is targeted. This URL is shown in Figure 6.1, along with other configuration parameters.

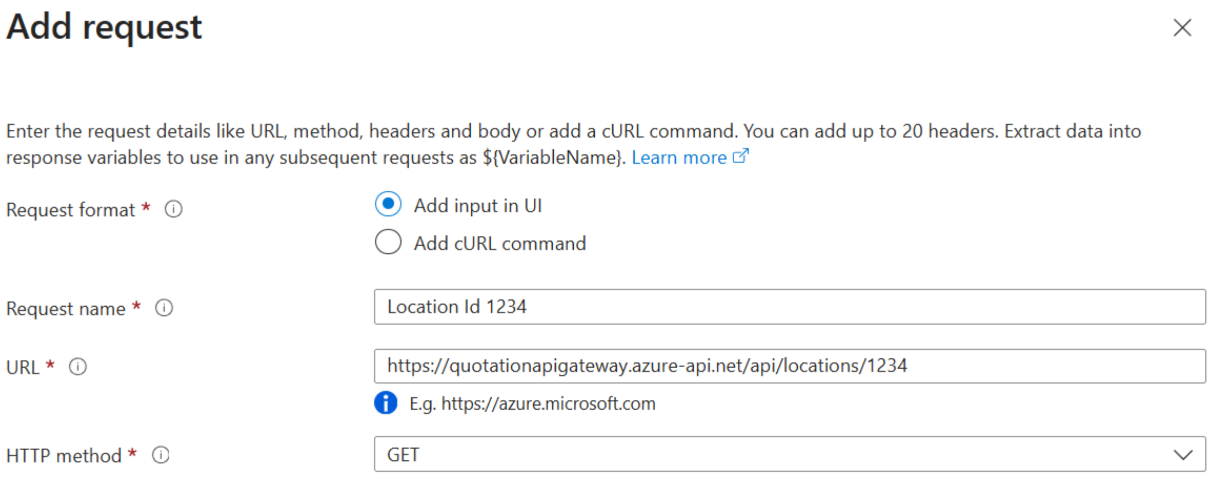


FIGURE 6.1. Performance Test Request Specification

Next, the load parameters are defined to match the scenario described in Subsection 6.3.1. These parameters specify the test duration (5 minutes), the warm-up period (2 minutes), and the warm-up load pattern (linear). The test duration includes the warm-up period. Additionally, 2 parallel engine instances each handle 100 concurrent virtual users, for a total of 200. Figure 6.2 shows these parameters.

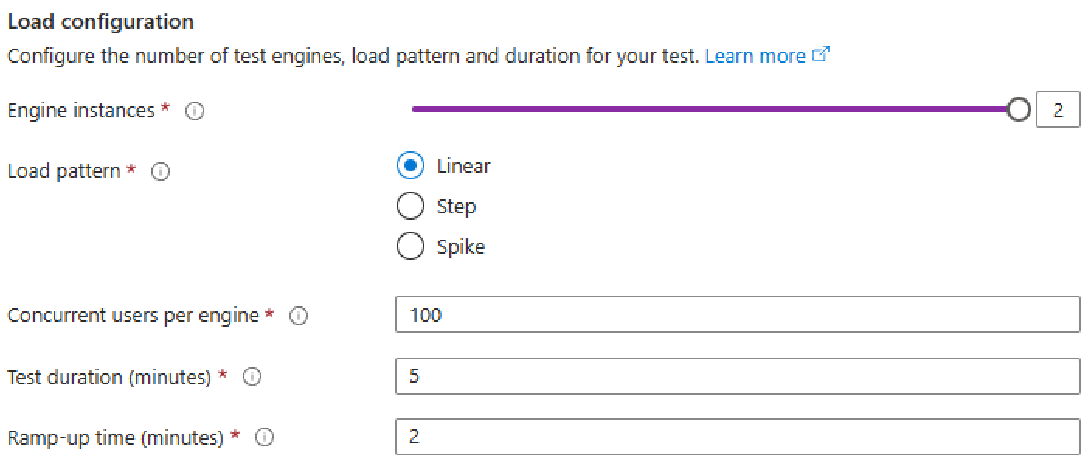
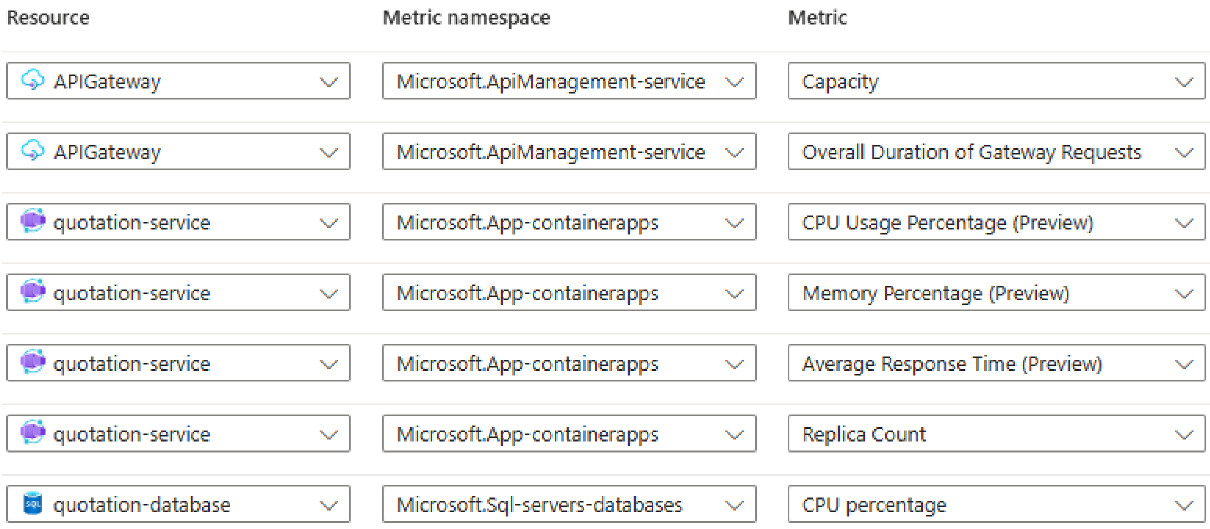


FIGURE 6.2. Performance Test Load Configuration

To generate the desired graphs and statistics, the performance test metrics must be specified. Although the most important metric is the total response time, a client-side metric that is collected by default, others are also useful. These include metrics related to the API Gateway, the Quotation Service's Container App, and the SQL Database associated with Quotation Service. These additional metrics help understand how the system performs and identify which component is responsible for potential bottlenecks. Figure 6.3 shows all selected metrics.



Resource	Metric namespace	Metric
APIGateway	Microsoft.ApiManagement-service	Capacity
APIGateway	Microsoft.ApiManagement-service	Overall Duration of Gateway Requests
quotation-service	Microsoft.App-containerapps	CPU Usage Percentage (Preview)
quotation-service	Microsoft.App-containerapps	Memory Percentage (Preview)
quotation-service	Microsoft.App-containerapps	Average Response Time (Preview)
quotation-service	Microsoft.App-containerapps	Replica Count
quotation-database	Microsoft.Sql-servers-databases	CPU percentage

Figure 6.3. Performance Test Metrics

The "Capacity" metric of the API Gateway is an Azure metric for API Management instances. It combines CPU usage, memory usage, and the queue length of incoming requests. This metric was chosen because more specific ones are only available in higher pricing tiers.

More metrics may be selected later, even after the performance test has been executed. This is useful in case the initial results warrant further analysis.

6.3.3. Performance Test Results and Analysis

The final test was executed on the 20th of September 2025, from 20:30:50 to 20:35:50 (UTC+1), making up the 5 minutes mentioned in Subsection 6.3.1.

Figure 6.4 shows the number of concurrent virtual users throughout the test. The number of users increases linearly for 2 minutes (the warm-up period). Then, this number remains constant for the remaining 3 minutes of the test. This evolution matches the configuration defined in Subsection 6.3.2.

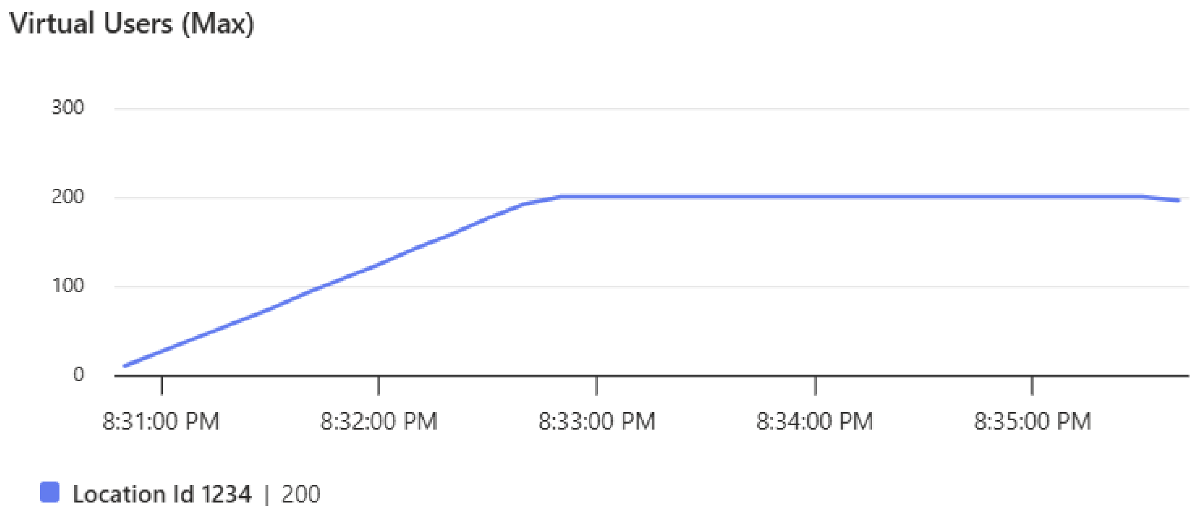


FIGURE 6.4. Concurrent Virtual Users During Performance Test

The next graphs shown in this subsection exclude the warm-up period, focusing on the actual test with a duration of 3 minutes.

Figure 6.5 shows the results for the most important metric: the total response time. It includes the average response time, the 90th percentile, and the 99th percentile. The 90th percentile for the total response time is 440.89 milliseconds. Therefore, Requirement 10 is satisfied, as the 90th percentile is below the threshold of 500 milliseconds.

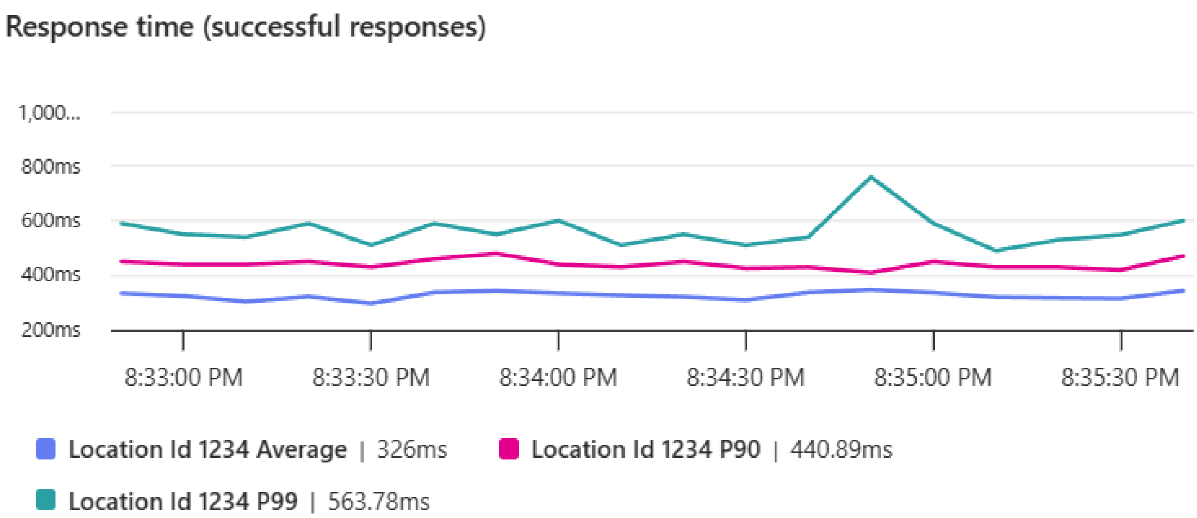


FIGURE 6.5. Total Response Time During Performance Test

Even though Requirement 10 is satisfied, it is still valuable to understand the causes behind the observed response times. That is, identifying which components are preventing this metric from being lower by analysing the other collected metrics.

Figure 6.6 shows the average response time of the Quotation Service's Container App. This value stands for the total time that the microservice takes to process a request, including database communication. The average response time is only 6.80 milliseconds, suggesting that the microservice and the database components are not responsible for bottlenecks.

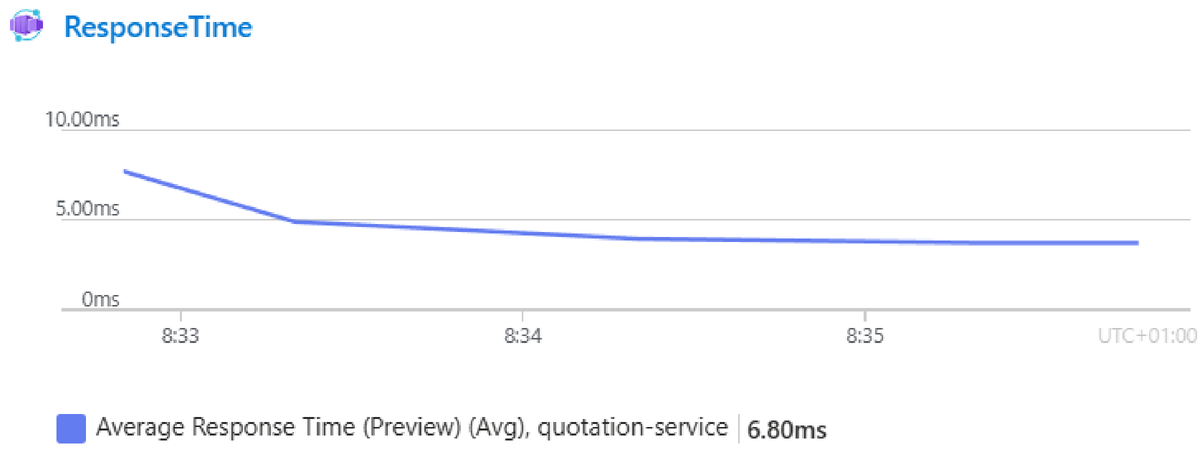


FIGURE 6.6. Quotation Service Response Time During Performance Test

Considering the metric presented in Figure 6.6, the API Gateway becomes the prime candidate for causing bottlenecks. Figure 6.7 shows the average duration that the API Gateway took to process a request. This duration encompasses the time taken since the API Gateway began processing a request until it received a response from Quotation Service and forwarded it to the client. The duration stayed below 60 milliseconds throughout the test, which is still much lower than the total response time.

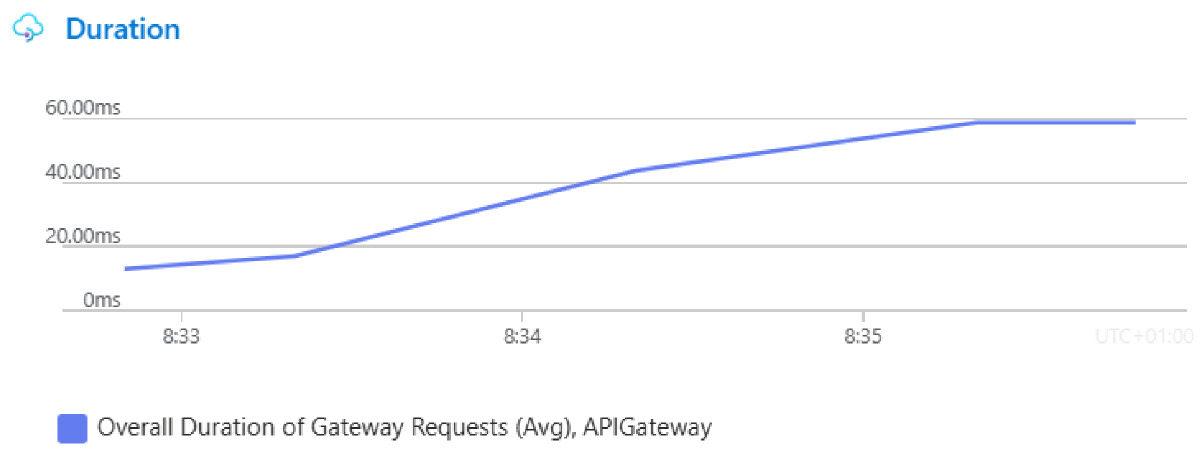


FIGURE 6.7. API Gateway Duration During Performance Test

However, the API Gateway's "Capacity" metric, shown in Figure 6.8, exposes a serious issue. The "Capacity" metric persisted at 100% for the entire duration of the actual test. This suggests that a big portion of incoming requests were queued before being processed, causing high total response times experienced by the virtual users.

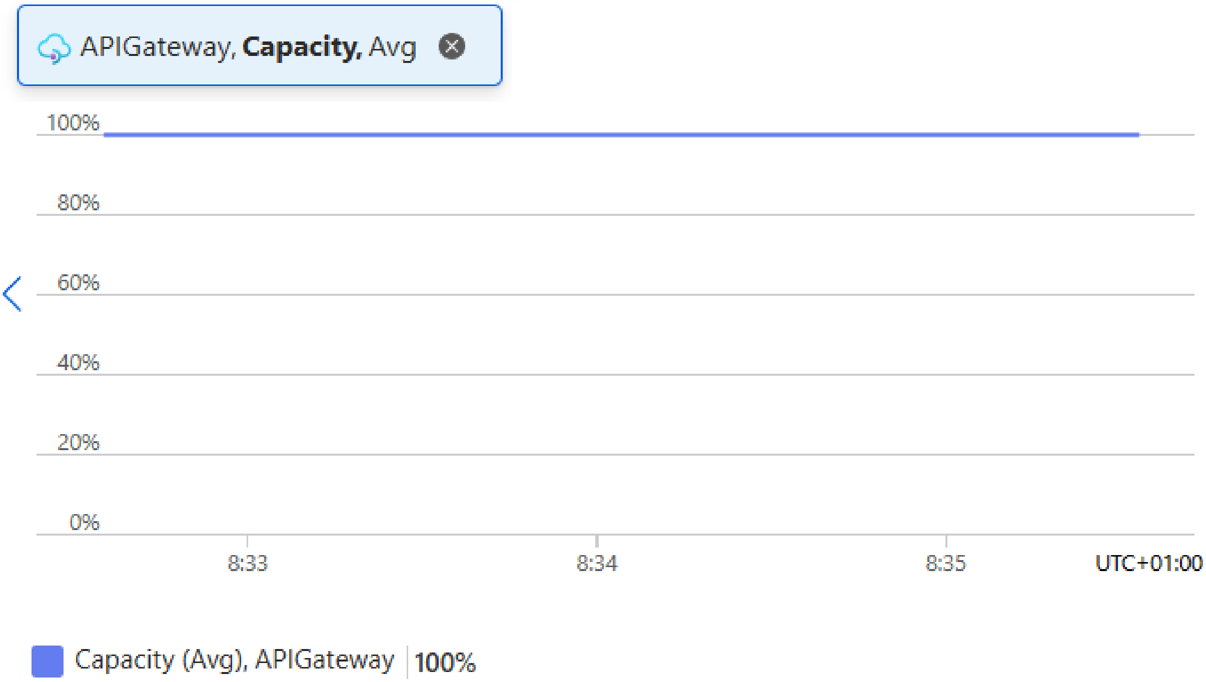


FIGURE 6.8. API Gateway Capacity During Performance Test

The next logical step would be to increase the processing capacity of the API Gateway. To do so, a higher pricing tier must be selected and another performance test must be executed. Due to budget limitations, this was not feasible.

Finally, Figure 6.9 lists the active Quotation Service replicas at one point during the test. This proves that the microservice environment was able to scale up in a decoupled way, fulfilling Requirement 8. Ultimately, most of these replicas were likely unnecessary, as the microservice was far from being the bottleneck.

Active revisions Inactive revisions **Replicas**

Name ↑	Ready	Running status	Restarts	Time created ↑
quotation-service--manual-7ffc7d4c84-68qxz	1/1	Running	0	9/20/2025, 8:31:38 PM
quotation-service--manual-7ffc7d4c84-8gz5z	1/1	Running	0	9/20/2025, 8:31:08 PM
quotation-service--manual-7ffc7d4c84-brgsd	1/1	Running	0	9/20/2025, 8:31:08 PM
quotation-service--manual-7ffc7d4c84-bz5b5	1/1	Running	0	9/20/2025, 8:31:38 PM
quotation-service--manual-7ffc7d4c84-dcj4b	1/1	Running	0	9/20/2025, 8:27:37 PM
quotation-service--manual-7ffc7d4c84-hs5hx	1/1	Running	0	9/20/2025, 8:27:37 PM
quotation-service--manual-7ffc7d4c84-mlqmr	1/1	Running	0	9/20/2025, 8:27:37 PM
quotation-service--manual-7ffc7d4c84-mnmdl	1/1	Running	0	9/20/2025, 8:31:08 PM
quotation-service--manual-7ffc7d4c84-vtt72	1/1	Running	0	9/20/2025, 8:27:37 PM
quotation-service--manual-7ffc7d4c84-w6b2d	1/1	Running	0	9/20/2025, 8:31:38 PM

FIGURE 6.9. Active Quotation Service Replicas During Performance Test

6.4. Requirements Fulfillment

All requirements delineated in Section 4.1 were fulfilled by the implemented web API. Table 6.3 summarizes how each requirement was satisfied and in which subsections the relevant information can be found.

Table 6.3: Requirements Fulfillment Explanation

Requirement	Fulfillment Explanation	Subsections
1	Quotation Service exposes an endpoint that takes a freight request. Quotation Service communicates with WebCargo Service or Cargofive Service to obtain freight rates from external APIs. These rates are used to calculate and provide freight quotes to the end user.	4.3.4, 4.3.6, 5.2.2
2	Whenever Quotation Service calculates freight quotes, it also stores the request and response data in its database. Users can retrieve their quotation history through a dedicated endpoint.	5.2.4
3	User Service uses authorization middleware to restrict access to the user search endpoint to only users with the "Administrator" role. User roles are stored in Entra ID and included in the access tokens it generates.	4.5.1, 5.2.6
4	Quotation Service provides an endpoint to search for airports and seaports.	5.2.5
5	User Service periodically polls Entra ID to check for deleted users. Upon user deletion, User Service sends a message batch to a Service Bus topic. Quotation Service subscribes to this topic and deletes the quote history of the deleted users.	4.3.5, 5.2.7
6	The API Gateway is responsible for authentication. It validates the access token for all endpoints whose functionality requires authentication. If the token is invalid or missing, the request is rejected.	4.3.1, 5.3.1
7	Each external carrier API integration is associated with a specific microservice. This distributed nature ensures that if one microservice fails, the others remain operational because they run independently, despite their need for intercommunication.	4.3.6, 4.2.3

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Requirement	Fulfillment Explanation	Subsections
8	Each microservice is deployed as a separate Azure Container App. Container Apps provide automatic scaling rules based on varying conditions. If a particular endpoint is under high load, the corresponding Container App will scale up to handle the increased demand.	4.2.3, 6.3.3
9	WebCargo Service and Cargofive Service cache freight rates obtained from their respective external carrier API for 1 day.	5.2.3
10	A performance test was conducted in Azure to evaluate the responsiveness of the web API. The results demonstrated that the 90th percentile of response times was below 500 milliseconds for the conditions specified in this requirement.	6.3.1, 6.3.3
11	The API Gateway is the only entry point for all client requests that interact with the web API's resources. Other than the Identity Provider, no other cloud components are publicly accessible.	4.3.1, 5.3.1, 5.3.2
12	User Service delegates account management to Entra ID, which implements the OAuth 2.0 and OIDC protocols. Therefore, the web API does not store any user credentials in its databases.	4.2.6, 5.2.7

CHAPTER 7

Conclusion

7.1. Concluding Remarks

This dissertation addressed the architectural challenges present when developing a complex server-side web API that integrates several distinct third-party APIs. The main research question concentrated on how to design and implement a software architecture capable of meeting the functional and non-functional requirements of such systems. The guiding hypothesis proposed that a cloud-based microservices architecture, orchestrated through an API Gateway, would be the most fitting solution.

To study the proposed hypothesis, a proof-of-concept web API was designed and implemented, with the freight forwarding industry as the business domain. The implementation integrated with two heterogenous external APIs: WebCargo for air transport and Cargofive for sea transport. The proposed web API adhered to a microservices pattern, where each microservice handled a specific business purpose, such as user-related logic, freight quote calculation, or interaction with one of the external carrier APIs. A cloud-native approach was employed, leveraging multiple PaaS services on the Microsoft Azure cloud platform. These cloud services were useful in many ways by providing microservice hosting, user identity management, databases, messaging functionality, a dedicated API Gateway service, and more.

The implemented artifact was evaluated to demonstrate its overall effectiveness. All 12 defined software requirements were successfully met, covering functionality, resilience, scalability, security, and performance. Specifically, a performance evaluation confirmed that the system could withstand 200 concurrent users while maintaining a 90th percentile response time of 440.8 milliseconds. In addition, the system demonstrated its ability to scale automatically and in a decoupled manner by creating replicas of a particular microservice based on the incoming request load.

In conclusion, the findings from the whole development process match the initial hypothesis. The decoupled nature of microservices provided resilience, maintainability, and scalability. A monolithic architecture would have made the source code of the web API less modular, prevented decoupled scaling, and decreased fault tolerance in case of a failure in a third-party service. The API Gateway simplified client communication and centralized authentication, shifting away responsibility from individual microservices. In addition, the cloud platform's PaaS services offered crucial components to the web API's architecture. This approach avoided upfront investments and time-consuming implementations of base functionality already provided by cloud platforms.

7.2. Academic Contributions

This dissertation details the design, implementation, and evaluation of a cloud-hosted web API that integrates with external APIs and cloud services. Existing literature on the subject tends to focus either on pure theoretical concepts or on specific architectural approaches. In contrast, this dissertation provides a more comprehensive view, covering multiple interconnected aspects: the structure and functionality of the web API's source code, integration with external APIs, cloud architecture, deployment pipelines, and a general evaluation of the proposed solution. No practical implementation found in literature covers all these aspects simultaneously. Therefore, this dissertation bridges this gap by presenting a complete implementation that integrates all these elements.

7.3. Limitations

The proposed solution has multiple limitations.

First, the development lifecycle was supposed to be accompanied by the business partner Devlop, but in practice, the company played a minor role. Although Devlop did offer initial guidance and provided the API keys to access the external carrier APIs, the company was unavailable for most of the development phase. This absence led to somewhat arbitrary software requirements, which guided the design and implementation of the web API.

Second, no unit or integration tests were implemented during the development process. The testing strategy relied only on manual testing. The increased complexity of the microservices architecture and the use of multiple cloud services complicate automated testing, making it a relevant topic for discussion.

Third, this dissertation does not consider some important tools that could have been used in the proposed solution. For example, container orchestration tools like Kubernetes[1], which automate the deployment, management, and scaling of containerized applications, were not explored. Furthermore, all cloud components were manually configured through the Azure Portal, which is convenient but less scalable than using Infrastructure as Code (IaC) tools like Terraform[2]. Besides, the absence of a dedicated caching approach for frequently accessed data, such as Redis Cache[3], constitutes a performance limitation.

Finally, the performance evaluation detailed in Section 6.3 is simplistic and tests only one endpoint of the web API. This provides a limited view of the performance capabilities of the proposed solution.

7.4. Future Work

In future work, the limitations mentioned in Section 7.3 could be addressed.

First, the software requirements should be more objective so that the web API as a whole better reflects real enterprise and end user needs. This could be achieved by a

[1]Kubernetes, `https://kubernetes.io/`, (accessed 24 Sep. 2025)
[2]Terraform, `https://www.terraform.io/`, (accessed 24 Sep. 2025)
[3]Redis Cache, `https://redis.io/docs/`, (accessed 24 Sep. 2025)

thorough involvement of a business partner in the development lifecycle or by studying real-world use cases.

Second, employing testing frameworks to implement unit and integration tests would increase the reliability of the proposed solution. Proper testing would prove the correctness of the web API's source code, preventing software bugs from affecting production environments.

Third, exploring the tools and specific technologies mentioned in Section 7.3 would increase the comprehensiveness of the research conducted in this research. This would involve investigating container orchestration tools, IaC tools, and dedicated caching alternatives.

Lastly, a more extensive performance evaluation that tests multiple endpoints and scenarios would help draw more accurate conclusions about the proposed solution's performance capabilities.

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