Software Design Specification

(GreenRoute)

Project Code:

BSCS-AWM-153435 -2025

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Project Manager's Signature

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Definition of Terms, Acronyms and Abbreviations

Term	Description
PWA	Progressive Web Application
DFD	Design Specification
GPS	Global Positioning System
ETA	Estimated Time of Arrival
IOS	iPhone Operating System
JS	JavaScript
API	Application Programming Interface
RBAC	Role Base Access Control
HTTP	Hypertext Transfer Protocol
SNDA	Serverless Real-Time Data architecture
UI	User Interface
GUI	Graphical User Interface
ER	Entity Relation
HTML	HyperText Markup Language

Table of Contents

1. Introduction

1.1 Purpose of Document

The purpose of this document is to describe what the Real-Time Web-Based Bus Tracking System will do and what is required to build it. It clearly explains the goals of the system, its main features, and how it should work so that everyone involved understands the same thing. This document helps guide the design, development, and testing of the project. It will be used to make sure the final system meets all the needs and expectations of its users.
This document will serve as a guide for all project stakeholders including the project manager, supervisor, development team and prospective users.

1.2 Project Overview

The project under study is a Real-Time Web-Based Bus Tracking System that allows users to view the live location of buses operating in Sargodha. The system uses GPS technology to collect the location of each bus and displays it on an interactive Google Map within a web application.
The software will be used by passengers to check the current position, route, and estimated arrival time of buses. Transport administrators can also use it to monitor bus movement, manage routes, and ensure that services are running on schedule. The system will be accessible through any device with an internet connection, such as a smartphone or computer.

Goals:

1. To provide accurate, real-time information about bus locations and arrival times.
2. To reduce passenger waiting time and improve transport reliability.
3. To support efficient route and fleet management for transport authorities.

Benefits:

1. Saves time and increases convenience for passengers.
2. Improves coordination between drivers and administrators.
3. Enhances trust and satisfaction in public transportation.
4. Contributes to the digital transformation of local transport systems.

1.3 Scope

The proposed system focuses on the development of a web-based real-time bus tracking platform designed specifically for the local E-Bus transport network launched under the initiative of Chief Minister Maryam Nawaz in Sargodha, Pakistan.
The boundaries of the proposed system are defined below to ensure clear deliverables.

In-Scope:

1. Designing and developing a responsive web application that displays real-time bus locations on an interactive Google Maps interface.
2. Utilizing GPS modules integrated within buses or drivers' mobile devices to capture live coordinate data.
3. Implementing a centralized backend database for continuous data synchronization and route management.
4. Providing users with essential transport details such as bus number, route, estimated arrival time (ETA), and current position.
5. Incorporating notification features to alert passengers of bus arrivals or route delays.
6. Ensuring the system's functionality and usability across desktop and mobile browsers through PWA design principles.

Out-of-Scope:

1. Integration with digital ticketing or payment systems.
2. Development of a dedicated native mobile application (Android/iOS).
3. Implementation of AI-based predictive analytics or route optimization algorithms.
4. Coverage of private, intercity, or non-governmental transport vehicles.
5. Operate offline; it will require an active internet connection for its services.

2. Design Considerations

The following section describes the key factors that influenced the system design decisions. It explains the assumptions made during development, the dependencies on external components and technologies, and the overall impact of these choices on system performance, scalability, and usability.

1.1 Assumptions and Dependencies

Following are assumptions and dependencies for the project that are already captured in the SRS document

Design Impact of Assumptions

The design must be capable enough of handling the limitations imposed by the core assumptions:

- **GPS-Enabled Devices and Active Tracking:**

- **Design Choice:** The system must be battery efficient for the Driver's smartphone to ensure continuous GPS and active tracking throughout the travel experience.
- **Implication:** The mobile driver component (an internal feature, basically a PWA wrapper for the GPS transmission) must be a very lightweight design and have minimal background processing.

- **Internet Access and Modern Browser:**
  - **Design Choice:** The frontend **(React.js PWA)** must follow **Progressive Web Application** principles to ensure it works smoothly on different devices and modern browsers (Chrome, Edge, Safari).
  - **Implication:** Design must be naturally adaptive.
- **Availability of Institutional Data/Permissions:**
  - **Design Choice:** The **Admin Dashboard** must include comprehensive features for managing bus routes and associated data, given that the transport authority provides the initial dataset.

Design Impact of Dependencies

The PWA's architecture is a cross-service integration, resulting in a design that depends on third party APIs and services:

- **Firebase Dependency:**
  - **Design Choice:** For live data handling the core architecture of our PWA must be centered on Firebase **Real time Database**.
  - **Implication:** Data in Firebase must be optimized for real-time reads and writes of latitude/longitude/timestamp data ensuring timely location updates.
- **Google Maps API Dependency:**
  - **Design Choice:** All functionalities related to map visualization, route drawing, and ETA computation will be based on the **Google Maps API**.
  - **Implication:** The React application needs a reliable and efficient component for managing API keys and handling map rendering.

1.2 Risks and Volatile Areas

Following are the potential areas of risks, that the system design must mitigate to make it efficient:

Risk/Volatile Area	Impact on Design	Contingency Path/Mitigation
Google Maps/Firebase Free-Tier Usage Limits	May experience service interruption or additional charges when traffic exceeds the free-tier limit.	**Mitigation:** Implement strict data transmission protocols to minimize unnecessary requests (e.g., sending updates only when the bus position significantly changes). **Contingency:** Design the backend data processing layer for seamless adaptability with both paid cloud services and self-hosted real-time databases if cost becomes a limitation.
Real-Time Data Inaccuracy	If GPS signal is weak or network is unstable, the bus location on the map will be delayed or varied irregularly.	**Mitigation:** Implement client-side smoothing algorithms on the frontend to estimate intermediate bus positions between official updates, providing smooth marker movement for the passenger. Implement a "Last Updated" timestamp display on each bus to inform users during poor connectivity areas.
Security and Data Privacy	Sensitive data (e.g., driver logs, passwords) could be compromised or exposed if security is not handled correctly.	**Mitigation: Force HTTPS encryption** for all client-server communication. **Centralize authentication** using Firebase Auth. Enforce **Role-Based Access Control (RBAC)** to restrict unauthorized users from admin/driver features.

Following are the potential upcoming developments, that we are considering for our system development:

Upcoming Developments	Design Impact	Recommended Design Strategy
Future Integration of Digital Ticketing	The current scope excludes payment systems, but are expected to be required in the future.	**Design Strategy (Modularity):** Design the Admin/User modules to be **modular** with clear separation of service layers. Ensure the user registration and login flow is independent from the tracking services so that a future payment module can be integrated as a separate microservice with minimum impact.

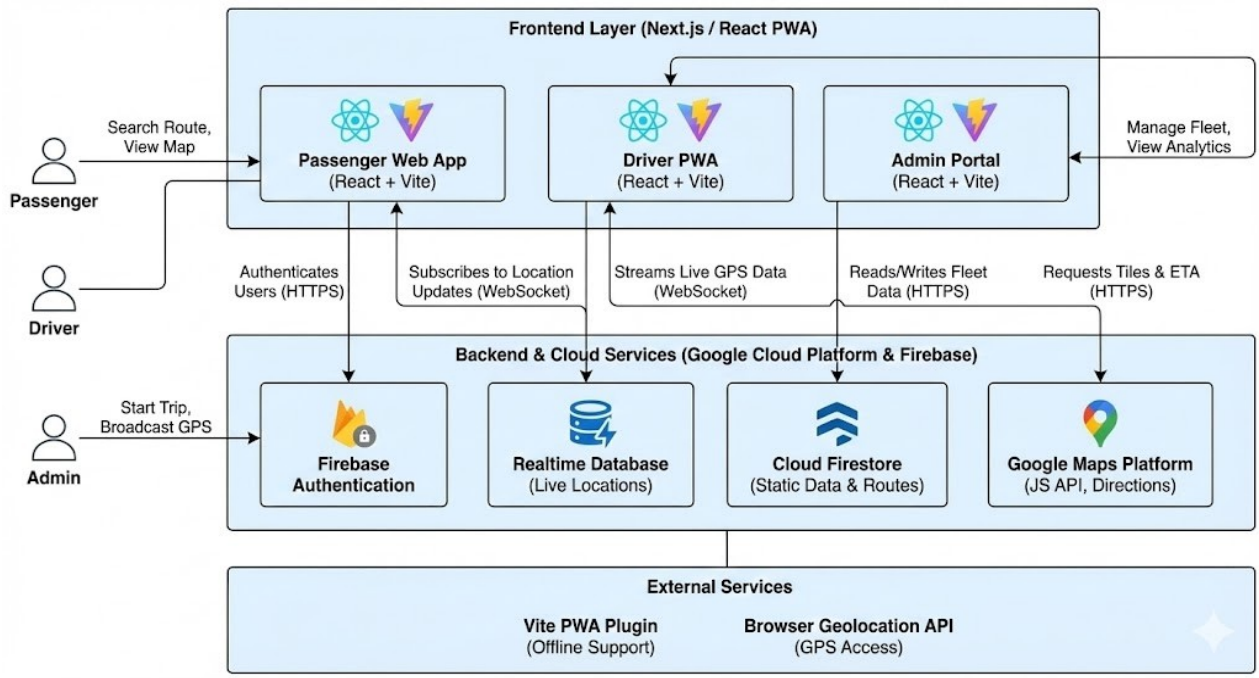
Future Native Mobile App Development	The current scope is PWA-only, but a native app is a common next step for better performance.	**Design Strategy (Technology Stack):** The use of Next.js for the frontend supports this approach, as it can be leveraged with React Native for subsequent native mobile application development, ensuring the initial front-end codes remain valuable.
Adding New Languages (English Only Constraint)	Currently supports English only, but a local project may need Urdu or other languages support	**Design Strategy (Internationalization):** Build the frontend using a framework that supports **internationalization (i18n)** from the start. All user-facing text should be extracted into language resource files, rather than being hard-coded in the React components.

3. System Architecture

The following system architecture overview describes the decomposition of system responsibilities across its primary subsystems. The diagrams below provide a visual mapping of the system hierarchy, from high-level design to sub-component execution.

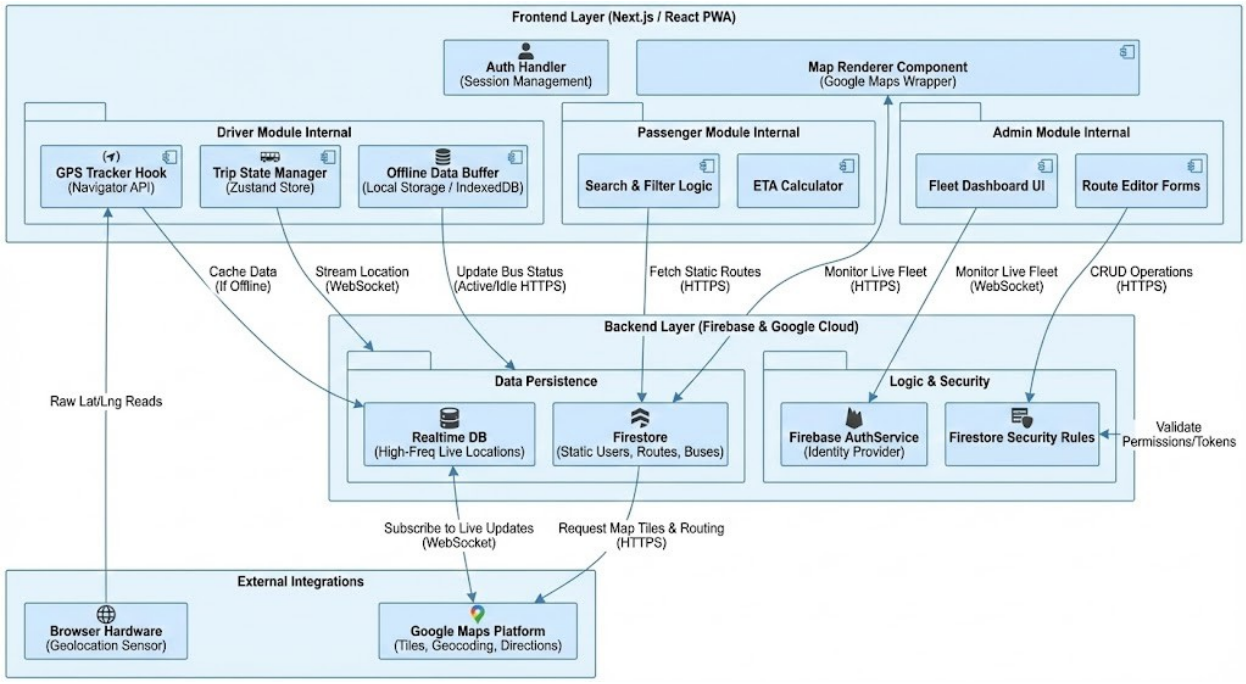
1.3 System Level Architecture

The system architecture provides a top-level architecture providing a foundation for more detailed design work.



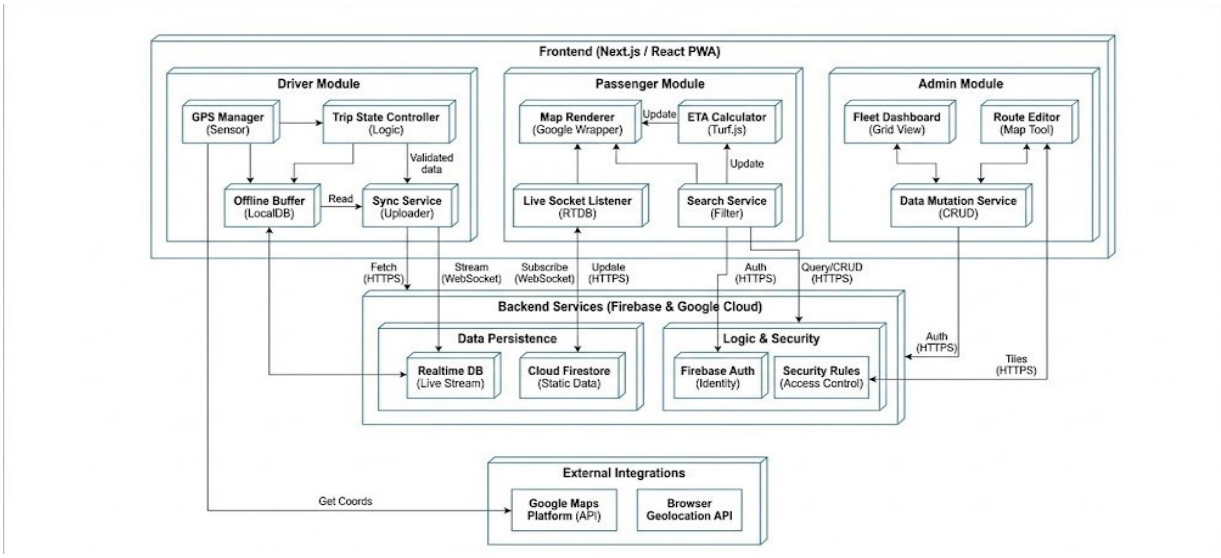
1.4 Sub-System / Component / Module Level Architecture

The following diagrams present the subsystems, components, and modules, showing their relationships and interactions.



1.5 Sub-Component / Sub-Module Level Architecture (1…n)

The following diagrams illustrate the decomposition of modules and components into subcomponents and submodules and their relationships.



4. Design Strategies

This section explains the key design strategies that govern the high-level structure and organization of the **GreenRoute**. These decisions ensure the project's non-functional requirements, such as performance, scalability, and maintainability.

1.6 Strategy 1: Serverless, Real-Time Data Architecture (SNDA)

The following sections present the design strategies considered for the system, detailing the reasoning behind each and areas of impact.

Area	Discussion and Reasoning	Trade-Offs
Data Management	The system is designed around the **Firebase Realtime Database**. This dictates a NoSQL data model optimized for speed and real-time synchronization. GPS data (latitude, longitude, timestamp) is pushed directly from the Driver application to Firebase, which acts as the central hub.	**Vendor Lock-In:** The system's dependency on Firebase may hinder flexibility and high costs for transitioning to a different hosting platform in future.
Concurrency & Synchronization	Firebase automatically handles updates from multiple buses drivers and	**Cost Sensitivity:** High-frequency updates from multiple

	broadcasts the latest locations to all connected users, avoiding the need to manage server-side real-time connections.	buses and users may lead to increase in Firebase usage cost.
System Reuse	The Firebase backend services are reusable for any future related application , as they provide a unified API.	**Data Complexity:** NoSQL data models (like Firebase's) complicates relational queries (e.g., finding all buses near a specific bus stop and calculating their ETA), requiring denormalization or extra cloud functions.

1.7 Strategy 2: Modular, Tiered Application Structure

The system is divided into self-contained modules for each main user role—Admin, Driver, and User and a core set of shared services. This structure ensures separation of concerns and facilitates future development.

Area	Discussion and Reasoning	Trade-Offs
Future System Extension	The system treats the **Admin Dashboard**, **User Portal**, and the **Driver Service** as separate modules, enabling new features like driver analytics—while maintaining the integrity of the core GPS tracking functionality.	**Increased Initial Complexity:** Developing the system with strict module boundaries and interfaces adds overhead to the initial setup compared with a single-tier architecture
System Reuse	The **Location Data Service** (the layer that reads from Firebase and interacts with the Google Maps API) is isolated. This service can be reused by any client (web, mobile, or third-party display boards) that needs real-time bus locations	**Inter-Module Communication:** Ensuring secure and reliable communication between the client apps and Firebase requires strict enforcement of security rules and consistent data formatting.
User Interface Paradigms	Each tier has a tailored interface: **Admins** have a desktop dashboard with full features, **Users** have a mobile-centric map view; and **Drivers** have a lightweight interface focused on GPS submissions	**Maintenance Overhead:** Maintaining three separate user interfaces, have same underlying frontend frameworks, increases testing and deployment overhead.

1.8 Strategy 3: Progressive Web Application (PWA) Client Design

The system will be delivered as a Progressive Web Application (PWA) using React.js. This addresses the requirement for a "Web-Based" solution while mitigating the performance and user experience shortcomings of a traditional web application.

Area	Discussion and Reasoning	Trade-Offs
User Interface Paradigms	PWA technology enables the system to be installed directly on a user's mobile device or desktop, offering an **app-like experience** with splash screens, icons, and full-screen mode, without relying on app stores.	**Limited Native Integration:** PWAs have reduced access to advanced device features as compared to native apps
Data Management	PWA capabilities allow **offline caching** of static assets, ensures the app shell loads quickly, enhancing perceived performance.	**Caching Management:** Managing service worker lifecycles and application updates requires careful version control, making it complex than conventional web development.
Concurrency and Synchronization	The use of **React' s component model** and state management facilitates efficient UI updates. Upon receiving real-time updates from Firebase, only the components displaying bus locations update, ensuring a smooth and non-blocking user experience.	**Initial Load Time:** The React bundle may take longer to load initially, potentially increasing first-load latency.

5. Detailed System Design

The following section presents all detailed system design diagrams and their corresponding descriptions.

1.9 Class Diagram Description

The system is structured around a central User class which is inherited by three specific actors: **Driver**, **Admin**, and **Passenger**. The operational logic involves *Bus*, *Route*, *Stop*, and *Notification* classes interacting to manage the transit network.

1. User Management Classes

- **Class: User (Abstract Class)**
    - **Description**: The base class representing any authenticated entity in the system.
    - **Attributes**:
        - **userID**: String {PK}: Primary key uniquely identifying the user.
        - **email**: String: User's contact email.
        - **passwordHash:** String: Secured storage of the user's password.
        - **fullName**: String: The full legal name of the user.
        - **createdAt**: DateTime: Timestamp of account creation.
    - **Methods**:
        - login(): Boolean: Authenticates the user into the system.
        - logout(): Void: Ends the current user session.
        - resetPassword(): Void: Initiates the password recovery process.
- **Class: Driver**
    - **Description**: Represents the bus operator responsible for trips.
    - **Attributes**:
        - driverID: String: Unique identifier for the driver.
        - licenseNumber: String: The driver's official license ID.
        - shiftStatus: Enum {ON_DUTY, OFF_DUTY}: Current working state.
        - currentBusID: String {FK}: Foreign key linking to the bus being driven.
    - **Methods**:
        - startTrip(routeID: String): Boolean: Begins a new journey on a specific route.
        - stopTrip(): Boolean: Ends the current journey.
        - broadcastGPS(lat: Float, lng: Float): Void: Transmits real-time location data.

- **Class: Admin**
    - **Description**: Represents the system manager.
    - **Attributes**:
        - adminID: String: Unique identifier for the administrator.
        - permissions: List<String>: A collection of access rights allowed for this admin.
    - **Methods**:
        - addBus(busDetails: Bus): Boolean: Registers a new bus in the fleet.
        - removeBus(busID: String): Boolean: Deletes a bus from the fleet.
        - updateRoute(routeDetails: Route): Void: Modifies existing route information.
        - viewSystemLogs(): List<Log>: Retrieves system activity records.

- **Class: Passenger**
  - **Description**: Represents the commuter using the app.
  - **Attributes**:
    - passengerID: String: Unique identifier for the passenger.
    - preferences: JSON: User-specific settings (e.g., saved routes).
  - **Methods**:
    - searchRoute(query: String): List<Route>: Finds routes matching user input.
    - viewLiveMap(busID: String): MapView: Opens the tracking interface for a bus.
    - getETA(stopID: String): Time: Calculates arrival time for a specific stop.

2. Operational Classes

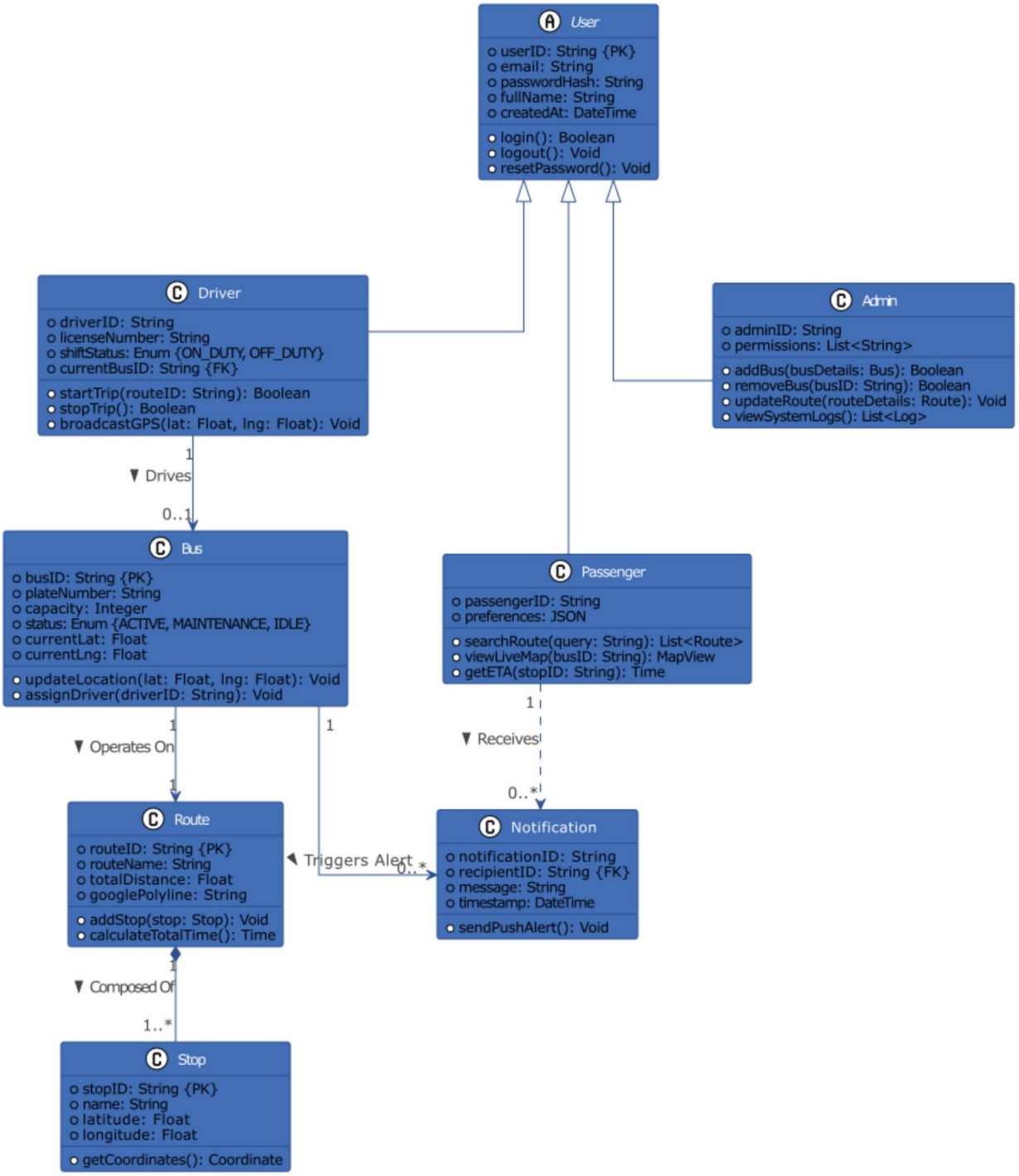
- **Class: Bus**
  - **Description**: Represents the physical vehicle in the fleet.
  - **Attributes**:
    - busID: String {PK}: Primary Key unique to the vehicle.
    - plateNumber: String: The vehicle's license plate.
    - capacity: Integer: Maximum number of passengers.
    - status: Enum {ACTIVE, MAINTENANCE, IDLE}: Current operational condition.
    - currentLat: Float: Current latitude coordinate.
    - currentLng: Float: Current longitude coordinate.
  - **Methods**:
    - updateLocation(lat: Float, lng: Float): Void: Updates the bus's position in the system.
    - assignDriver(driverID: String): Void: Links a driver to the bus.

- **Class: Route**
  - **Description**: Defines the path and schedule a bus follows.
  - **Attributes**:
    - routeID: String {PK}: Primary Key for the route.
    - routeName: String: Descriptive name of the route.
    - totalDistance: Float: The full length of the route.
    - googlePolyline: String: Encoded string for map visualization.
  - **Methods**:
    - addStop(stop: Stop): Void: links a new stop to the route.
    - calculateTotalTime(): Time: Computes the estimated duration of the route.

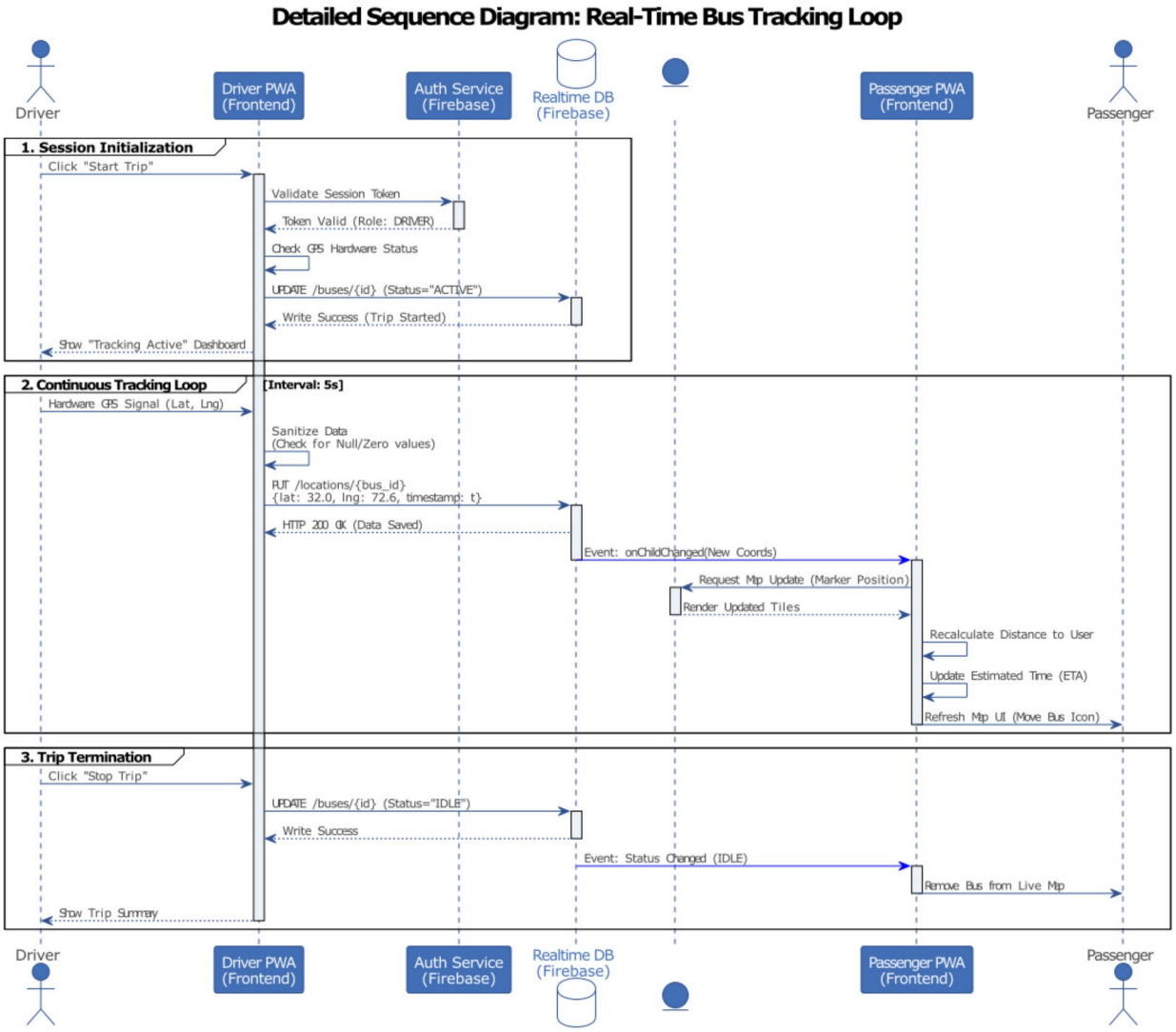
- **Class: Stop**
    - **Description**: Represents a physical location where the bus halts.
    - **Attributes**:
        - stopID: String {PK}: Primary Key for the stop.
        - name: String: The human-readable name of the stop.
        - latitude: Float: GPS Latitude.
        - longitude: Float: GPS Longitude.
    - **Methods**:
    - getCoordinates(): Coordinate: Returns the location object of the stop.

3. Support Classes

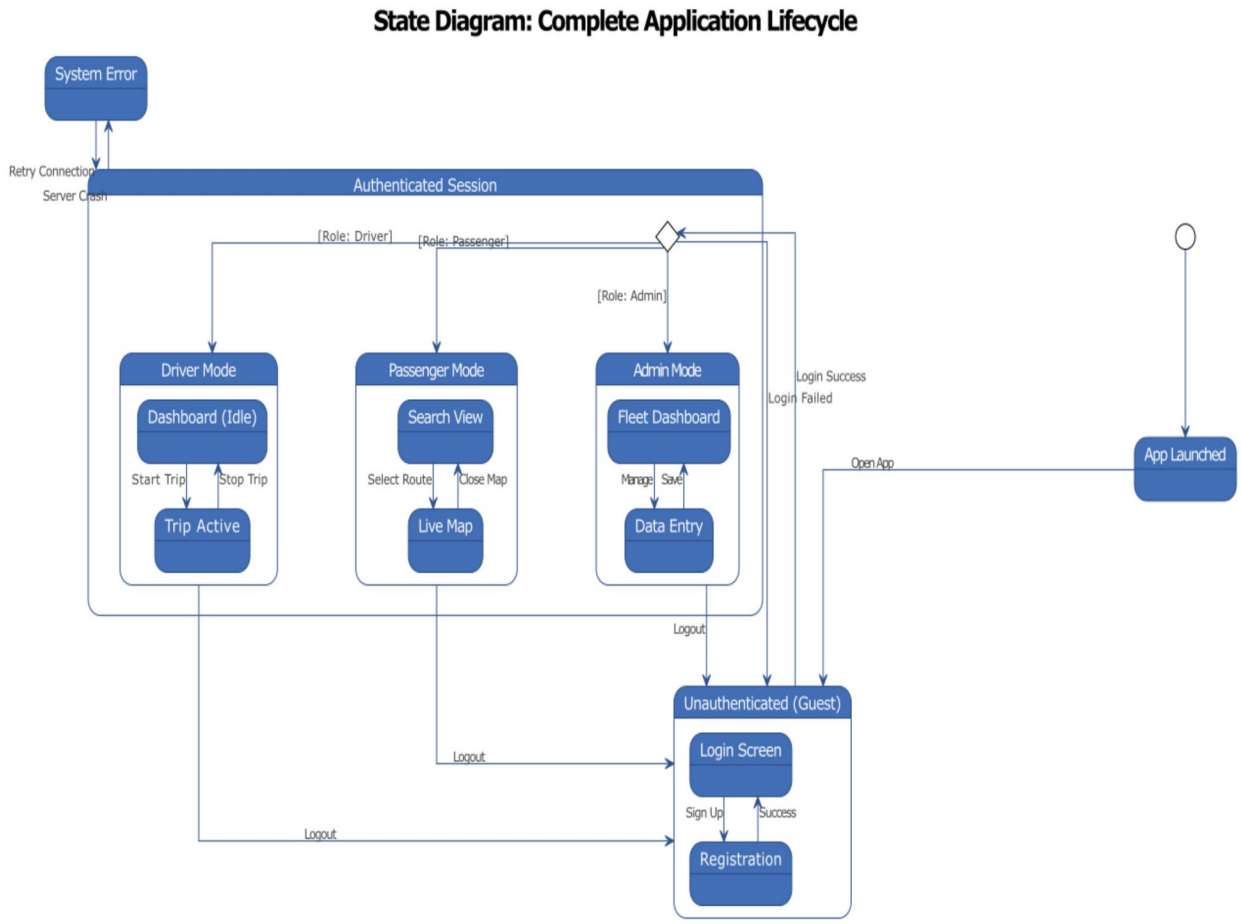
- **Class: Notification**
    - **Description:** Manages alerts sent to users.
    - **Attributes**:
        - notificationID: String: Unique ID for the alert.
        - recipientID: String {FK}: Foreign Key linking to the receiving User.
        - message: String: Text content of the alert.
        - timestamp: DateTime: Time the alert was created.
    - **Methods**:
        - sendPushAlert(): Void: Dispatches the notification to the device.



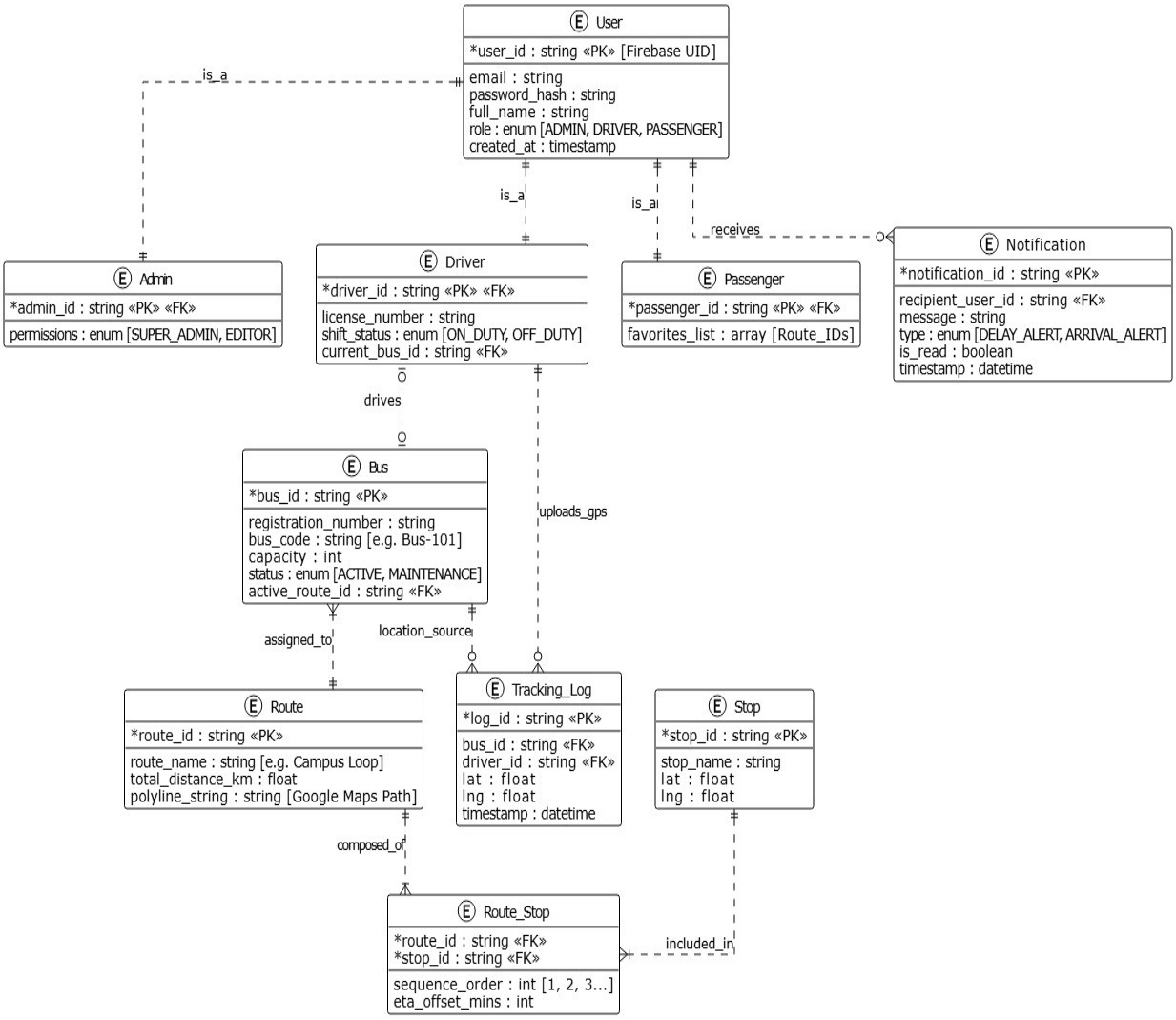
1.10 Sequence Diagram



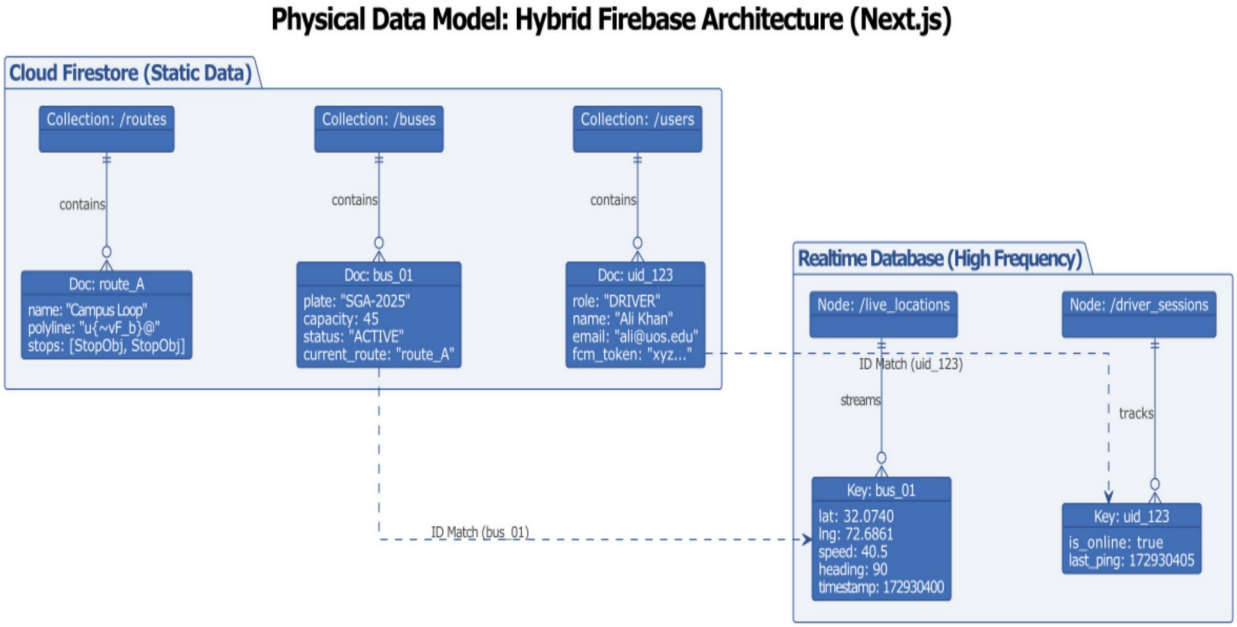
1.11 State Transition Diagram



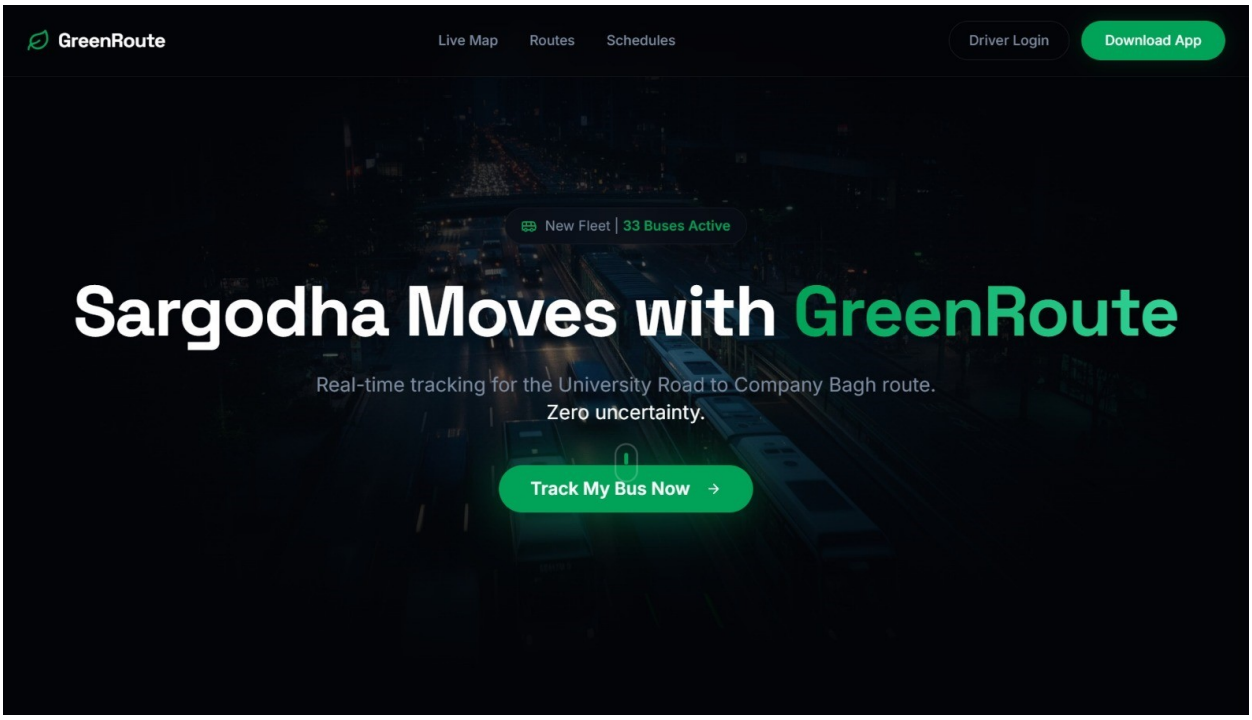
1.12 Logical data model (E/R model)

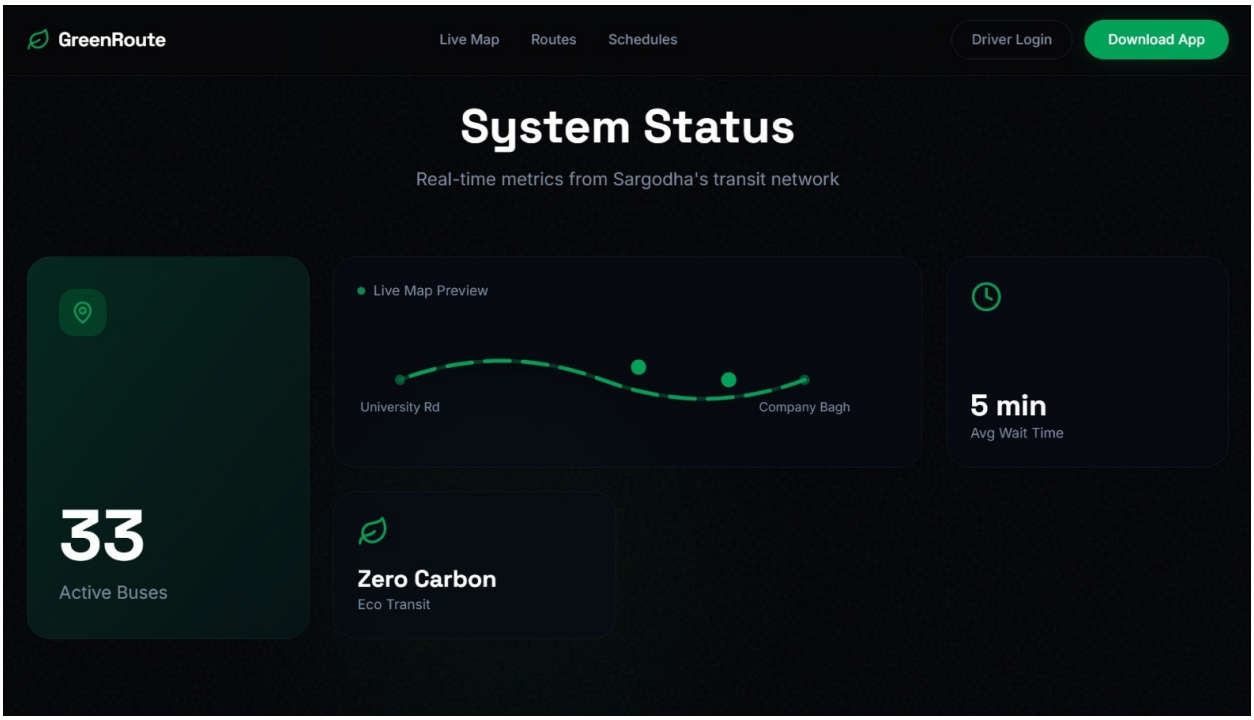


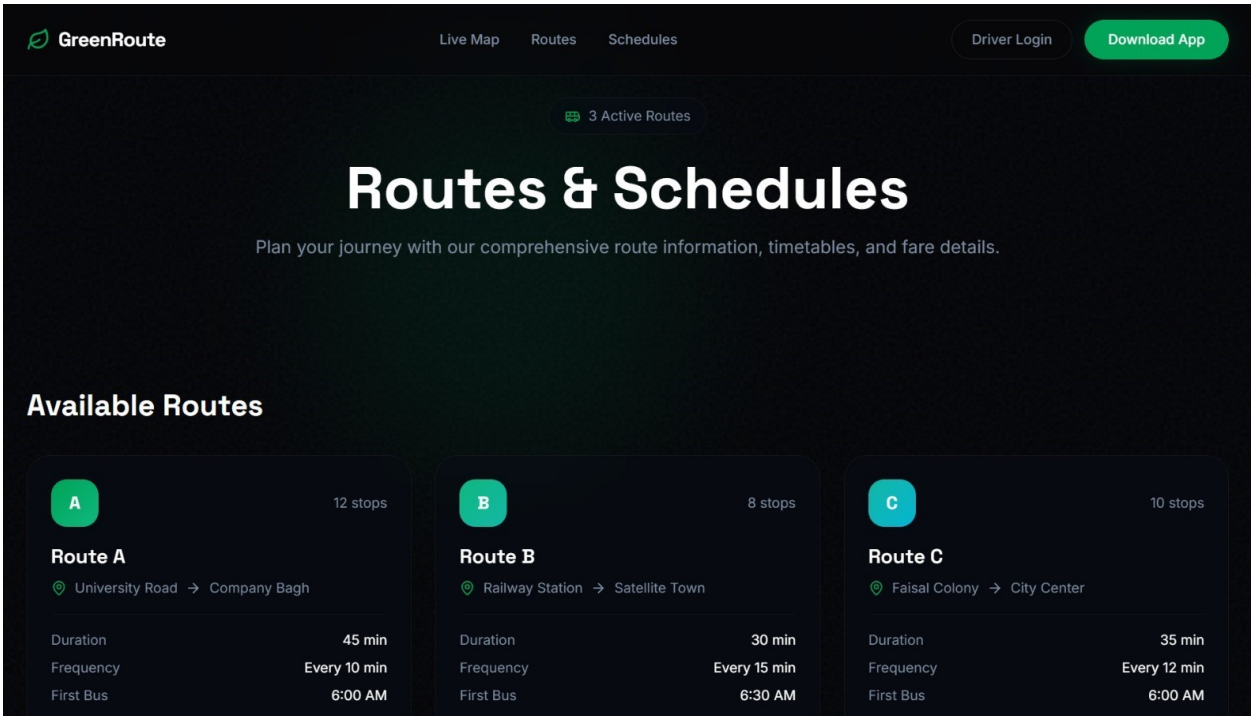
1.13 Physical data models

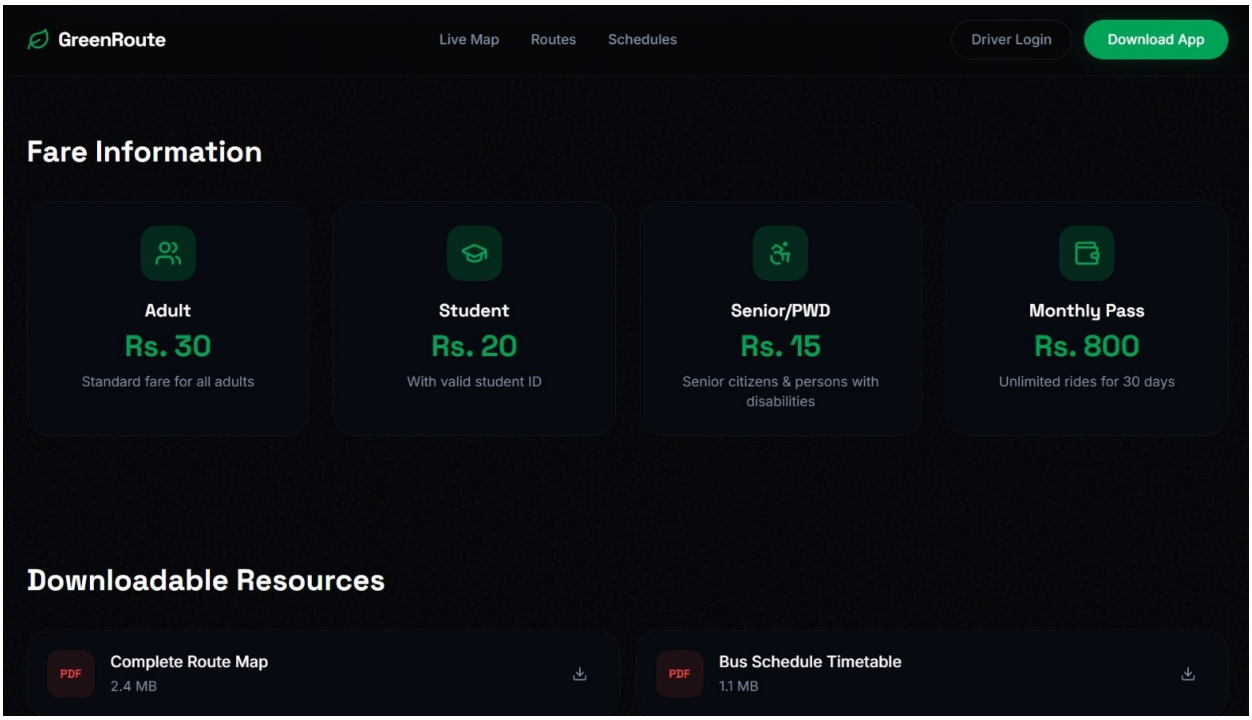

Physical Data Model: Hybrid Firebase Architecture (Next.js)
Cloud Firestore (Static Data)
Collection: /routes
Collection: /buses
Collection: /users
contains
contains
contains
Doc: route_A
name: "Campus Loop"
polyline: "u{~vF_b}@"
stops: [StopObj, StopObj]
Doc: bus_01
plate: "SGA-2025"
capacity: 45
status: "ACTIVE"
current_route: "route_A"
Doc: uid_123
role: "DRIVER"
name: "Ali Khan"
email: "ali@uos.edu"
fcm_token: "xyz..."
Realtime Database (High Frequency)
Node: /live_locations
Node: /driver_sessions
ID Match (uid_123)
streams
tracks
ID Match (bus_01)
Key: bus_01
lat: 32.0740
lng: 72.6861
speed: 40.5
heading: 90
timestamp: 172930400
Key: uid_123
is_online: true
last_ping: 172930405

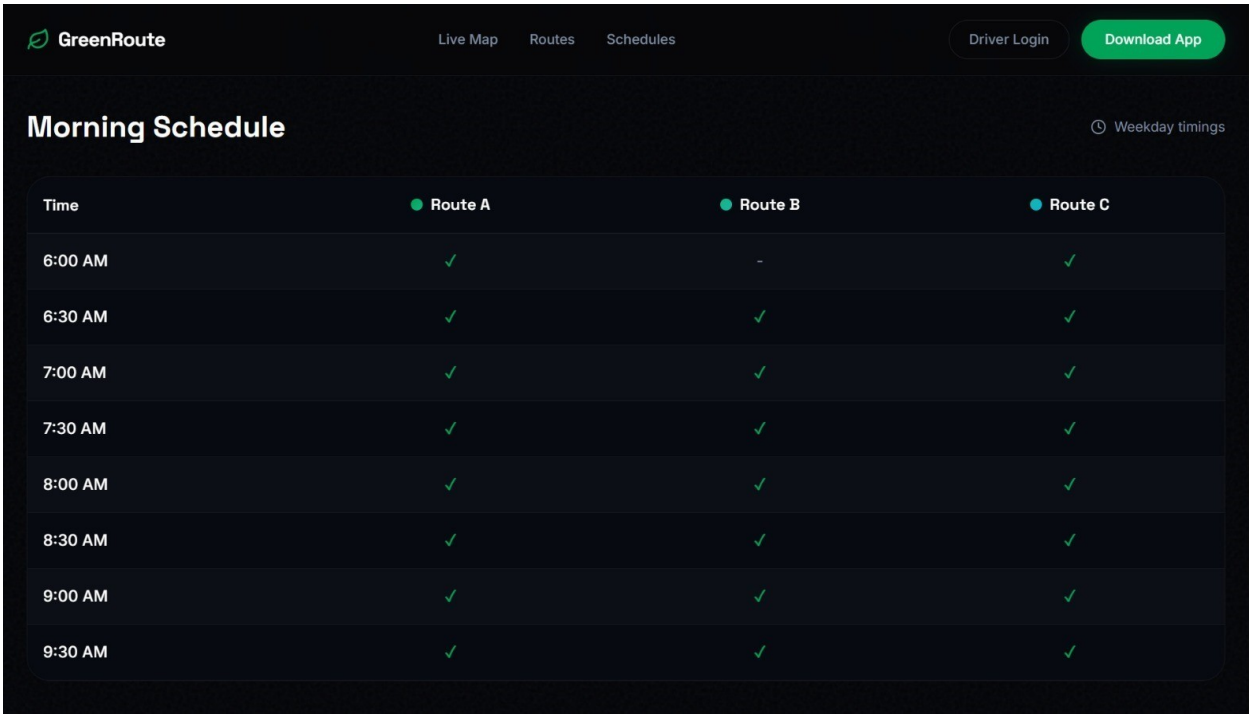
1.14 GUIs


GreenRoute
Live Map
Routes
Schedules
Driver Login
Download App
New Fleet | 33 Buses Active
Sargodha Moves with GreenRoute
Real-time tracking for the University Road to Company Bagh route.
Zero uncertainty.
Track My Bus Now


GreenRoute
Live Map
Routes
Schedules
Driver Login
Download App
System Status
Real-time metrics from Sargodha's transit network
Live Map Preview
University Rd
Company Bagh
5 min
Avg Wait Time
33
Active Buses
Zero Carbon
Eco Transit

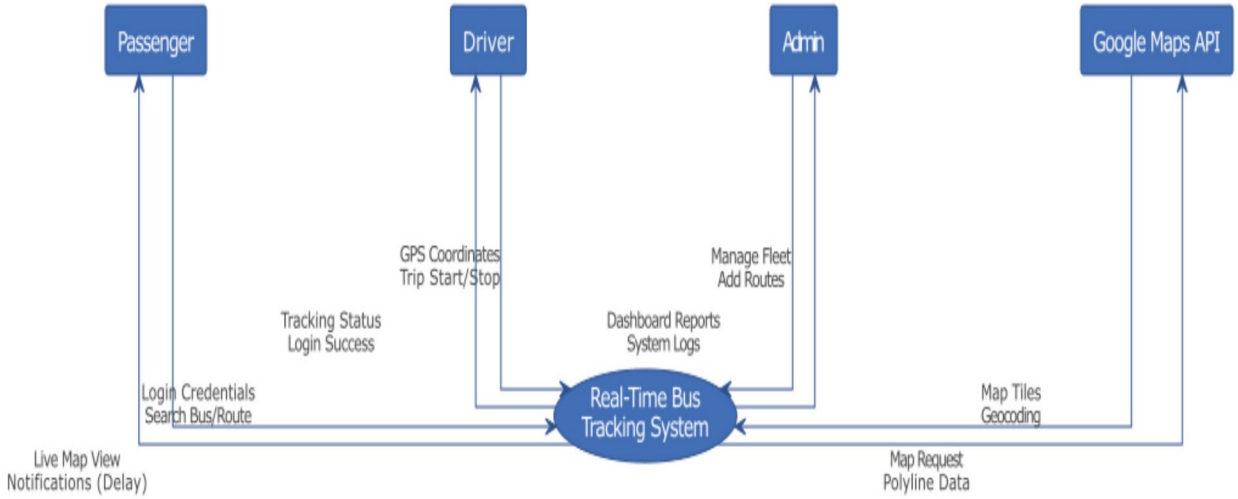

GreenRoute
Live Map
Routes
Schedules
Driver Login
Download App
3 Active Routes
Routes & Schedules
Plan your journey with our comprehensive route information, timetables, and fare details.
Available Routes
A
12 stops
Route A
University Road → Company Bagh
Duration 45 min
Frequency Every 10 min
First Bus 6:00 AM
B
8 stops
Route B
Railway Station → Satellite Town
Duration 30 min
Frequency Every 15 min
First Bus 6:30 AM
C
10 stops
Route C
Faisal Colony → City Center
Duration 35 min
Frequency Every 12 min
First Bus 6:00 AM


GreenRoute
Live Map
Routes
Schedules
Driver Login
Download App
Fare Information
Adult
Rs. 30
Standard fare for all adults
Student
Rs. 20
With valid student ID
Senior/PWD
Rs. 15
Senior citizens & persons with disabilities
Monthly Pass
Rs. 800
Unlimited rides for 30 days
Downloadable Resources
PDF
Complete Route Map
2.4 MB
PDF
Bus Schedule Timetable
1.1 MB

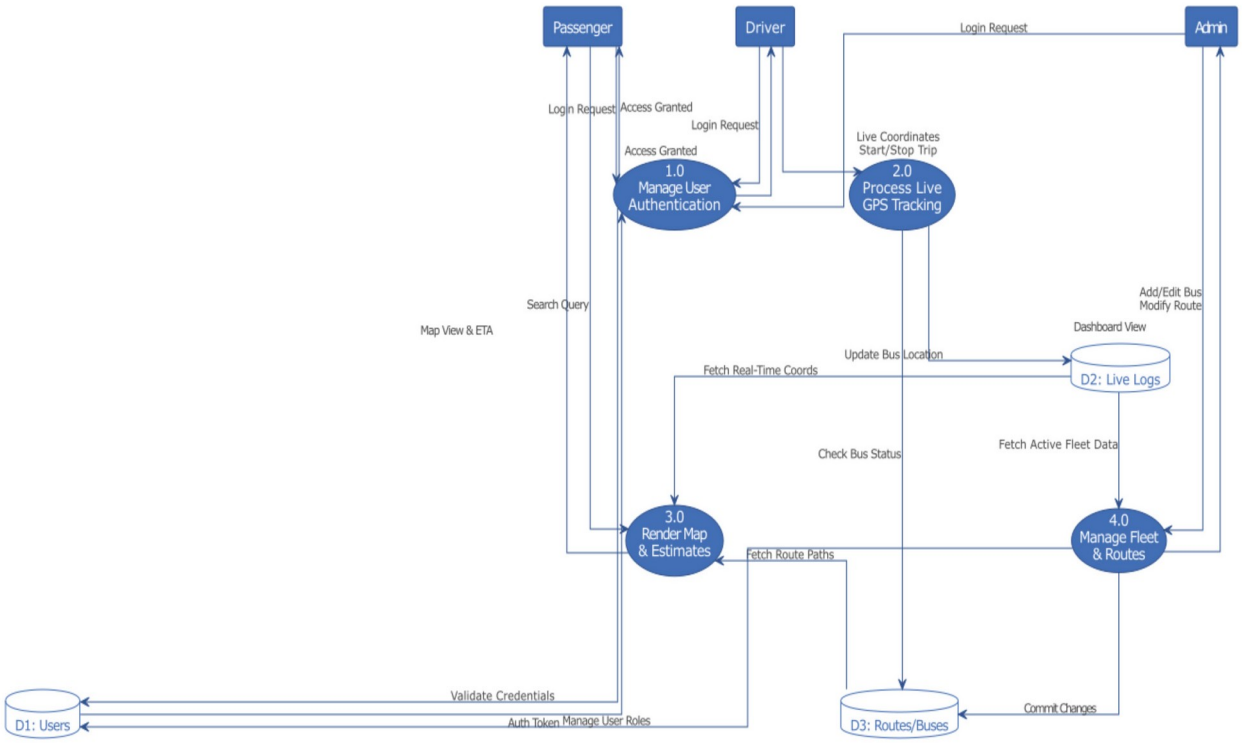

GreenRoute
Live Map
Routes
Schedules
Driver Login
Download App
Morning Schedule
Weekday timings
Time
Route A
Route B
Route C
6:00 AM
6:30 AM
7:00 AM
7:30 AM
8:00 AM
8:30 AM
9:00 AM
9:30 AM

1.15 Data Flow Diagrams

1.15.1 DFD Level 0



1.15.2 DFD Level 1



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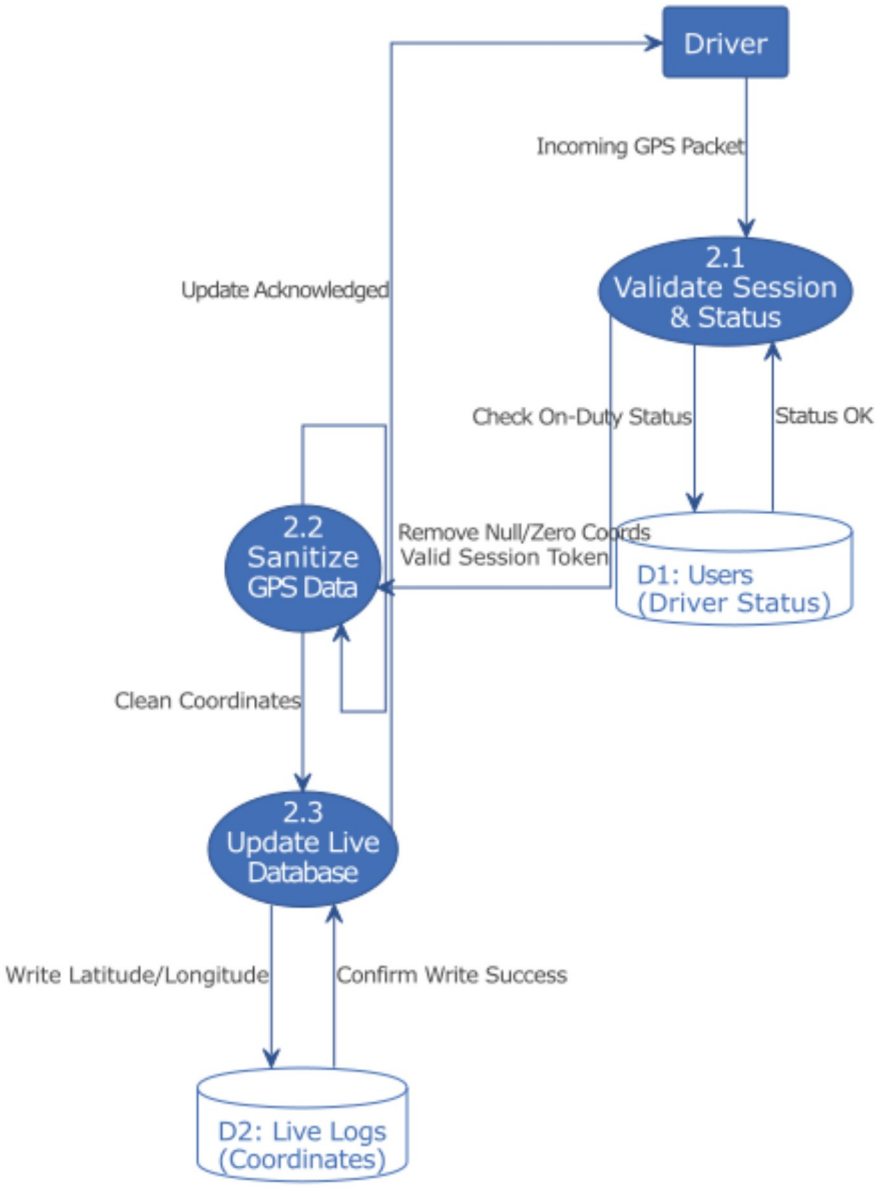

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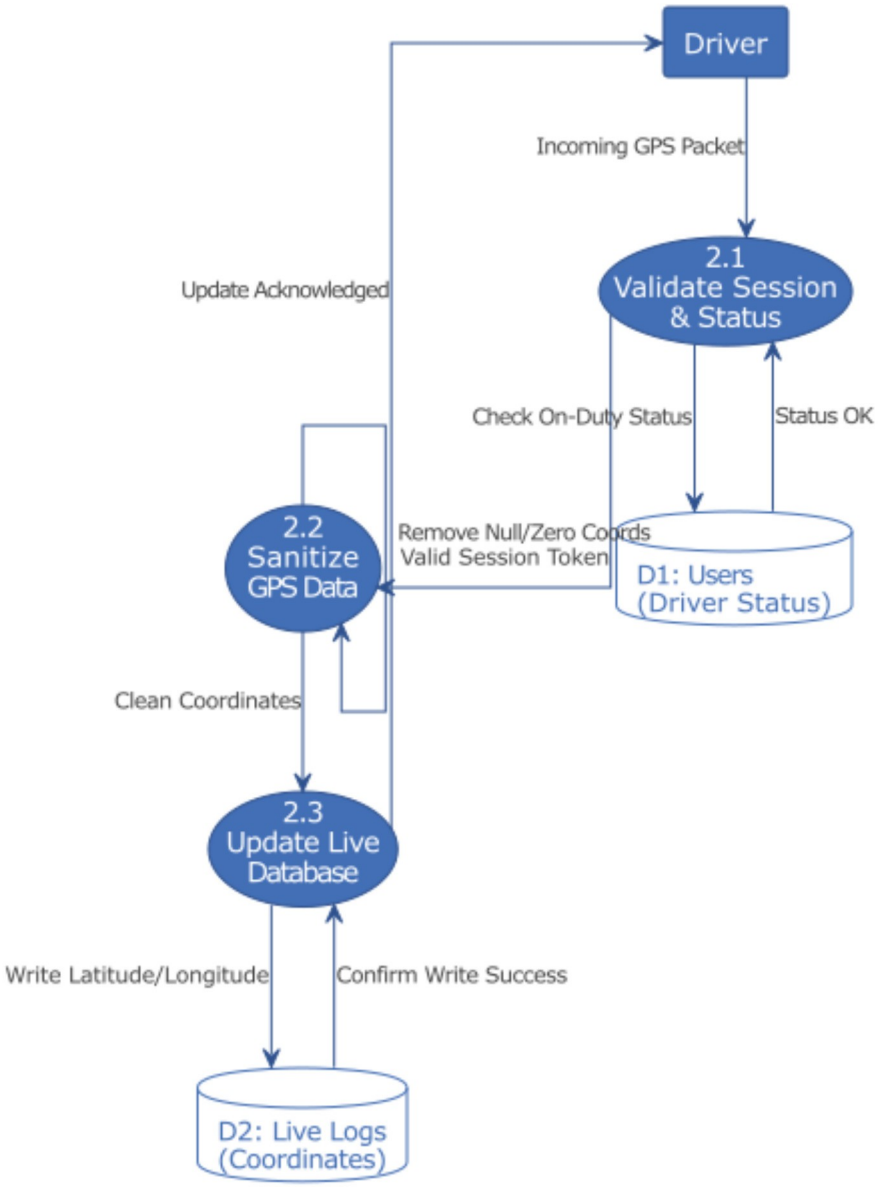

6. References

Ref. No.	Document Title	Date of Release/ Publication	Document Source
1	Project Proposal	Oct 6, 2025	https://github.com/Asma-Khanum1722/FYP-Project.git
2	Software Requirements Specification	Oct 20, 2025	https://github.com/Asma-Khanum1722/FYP-Project.git