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AUTOMATED BUS SCHEDULING AND ROUTE MANAGEMENT APPLICATIONS

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A B S T R A C T

A microservice-based bus route management system built with Docker and Google Cloud Run is presented in this article. Issues with scheduling, manpower management, and route optimization hinder the effectiveness of public transportation. Our suggested Automated Bus Scheduling and Route Management System gives administrators and crew members role-based access and optimizes routes using the LKH algorithm. The system employs a proprietary scheduling algorithm that allows bus stop clustering, efficient route construction, and workforce scheduling while taking peak hours and working hour limits into account. Leaflet is used for real-time mapping visualization. Interactive mapping, automatic scheduling with demand-driven modifications, and extensive tools for scheduling, managing personnel assignments, bus stops, routes, and schedules via an integrated dashboard are some of the key features.

KEYWORDS: *microservice architecture, transportation management system, route optimization, LKH algorithm, Docker containerization, Google Cloud Run, Leaflet mapping, schedule optimization, public transit management, peak hour management, workforce scheduling*

INTRODUCTION

Effective public transportation systems are fundamental to urban mobility, serving as the backbone of sustainable city development. However, conventional transit operations face substantial challenges in three critical areas: route optimization, scheduling efficiency, and workforce management. These challenges significantly impact on service reliability, operational costs, and ultimately, passenger satisfaction.

To address these persistent issues, we present a comprehensive microservice-based Automated Bus Scheduling and Route Management System deployed using Google Cloud Run and Docker containerization. Our solution integrates the powerful Lin-Kernighan-Helsgaun (LKH) algorithm for route optimization with a proprietary scheduling engine to transform how transportation authority's manage their operations.

The system's architecture employs a dual-access approach, providing tailored interfaces for both administrative personnel and ground crew members. Administrators can define bus stops, depots, and operational priorities through an intuitive interface, while the system dynamically clusters these locations and calculates optimized routes. The integration of Leaflet mapping technology enables real-time visualization of transportation networks, enhancing both operational oversight and planning capabilities.

A distinguishing feature of our system is its sophisticated approach to workforce management. The scheduling algorithm automatically assigns drivers and conductors to routes while balancing workload distribution, adhering to labor regulations, and accounting for necessary rest periods. This human-centered approach to scheduling ensures both operational efficiency and employee wellbeing.

The system delivers four primary capabilities that transform transportation management:

- Route Optimization: The LKH algorithm generates efficient bus routes based on strategic stop clustering, minimizing travel distance while maximizing coverage.
- Dynamic Scheduling: Our proprietary algorithm optimizes employee assignments across routes, ensuring balanced workloads while respecting working hour constraints. [6]
- Interactive Mapping: The Leaflet-based interface provides transportation managers with powerful visualization tools for real-time monitoring and adjustment of stops, depots, and routes.
- Demand-Responsive Operations: The scheduling engine incorporates peak period analysis and passenger demand patterns to allocate resources efficiently throughout the day.

By seamlessly integrating these capabilities within a microservice architecture, our system offers transportation authorities unprecedented operational control, enhanced service reliability, and significant efficiency improvements. The containerized deployment through Google Cloud Run ensures scalability and maintainability, allowing the system to adapt to the evolving needs of modern transportation networks.

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METHODOLOGY

Our strategy for creating the Automated Bus Scheduling and Route Management System utilizes a systematic methodology that combines microservice architecture with tailored algorithms for optimizing transportation. This segment details the technical framework and methodology processes that support our system.

A. System Architecture Design

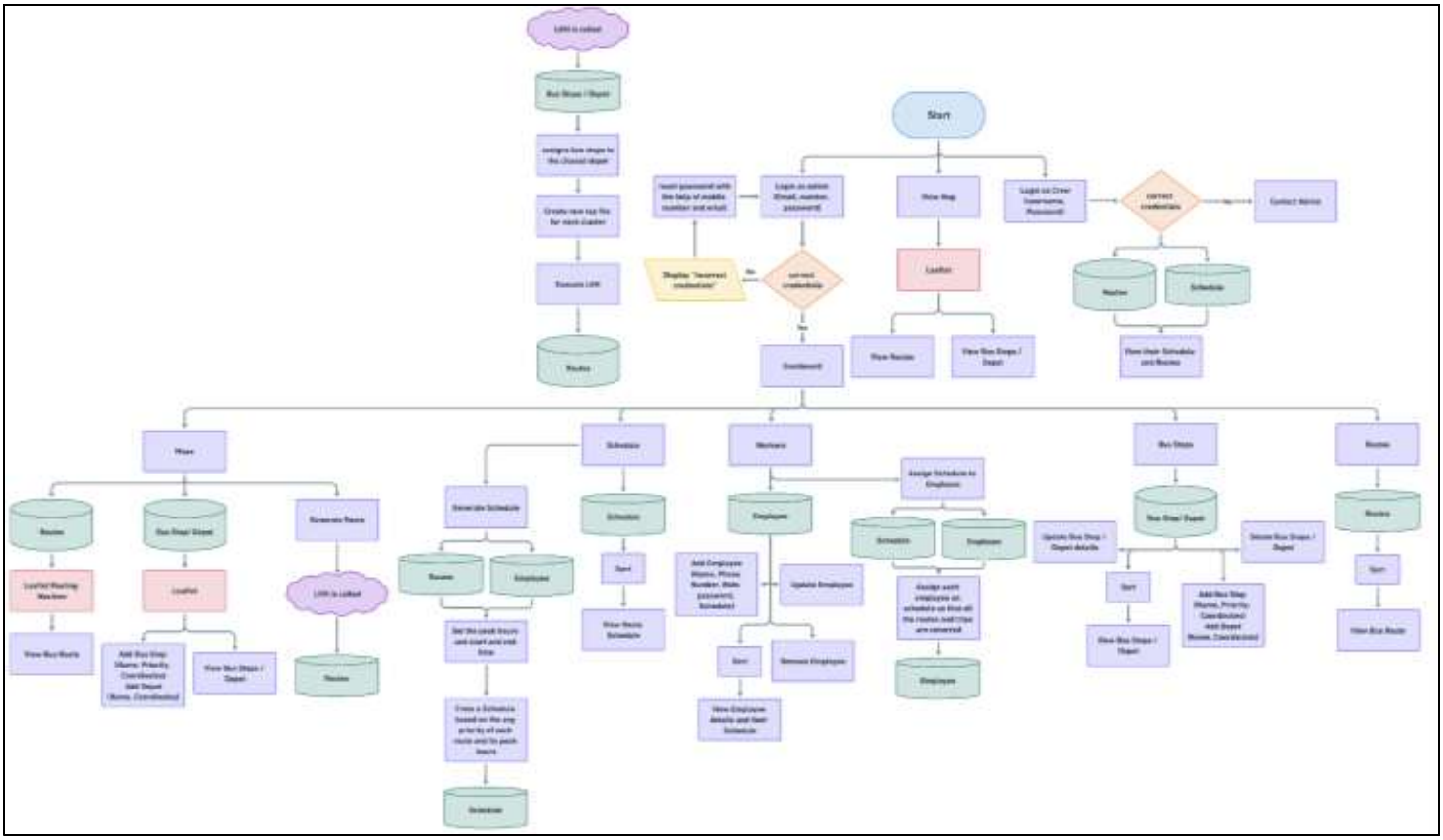

Fig 1. Flow Chart

The system utilizes containerized microservice architecture hosted on Google Cloud Run, with each functional unit enclosed within Docker containers. This architecture offers numerous advantages:

1. Scalability: Separate components can independently scale according to demand, guaranteeing efficient resource utilization.
2. Resilience: Container isolation averts cascading failures throughout the system.
3. Deployment Efficiency: Continuous integration and deployment pipelines streamline the testing and deployment process.

The system is segmented into multiple interconnected microservices, each tasked with a specific area of functionality:

- Authentication Service: Oversees user authentication and role-based access control
- Bus Stop Management Service: Manages CRUD operations for bus stops and depots
- Route Optimization Service: Applies the LKH algorithm for calculating routes [3]
- Scheduling Service: Implements the proprietary scheduling algorithm
- Mapping Service: Integrates with Leaflet to offer visualization capabilities

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B. Data Flow and Processing

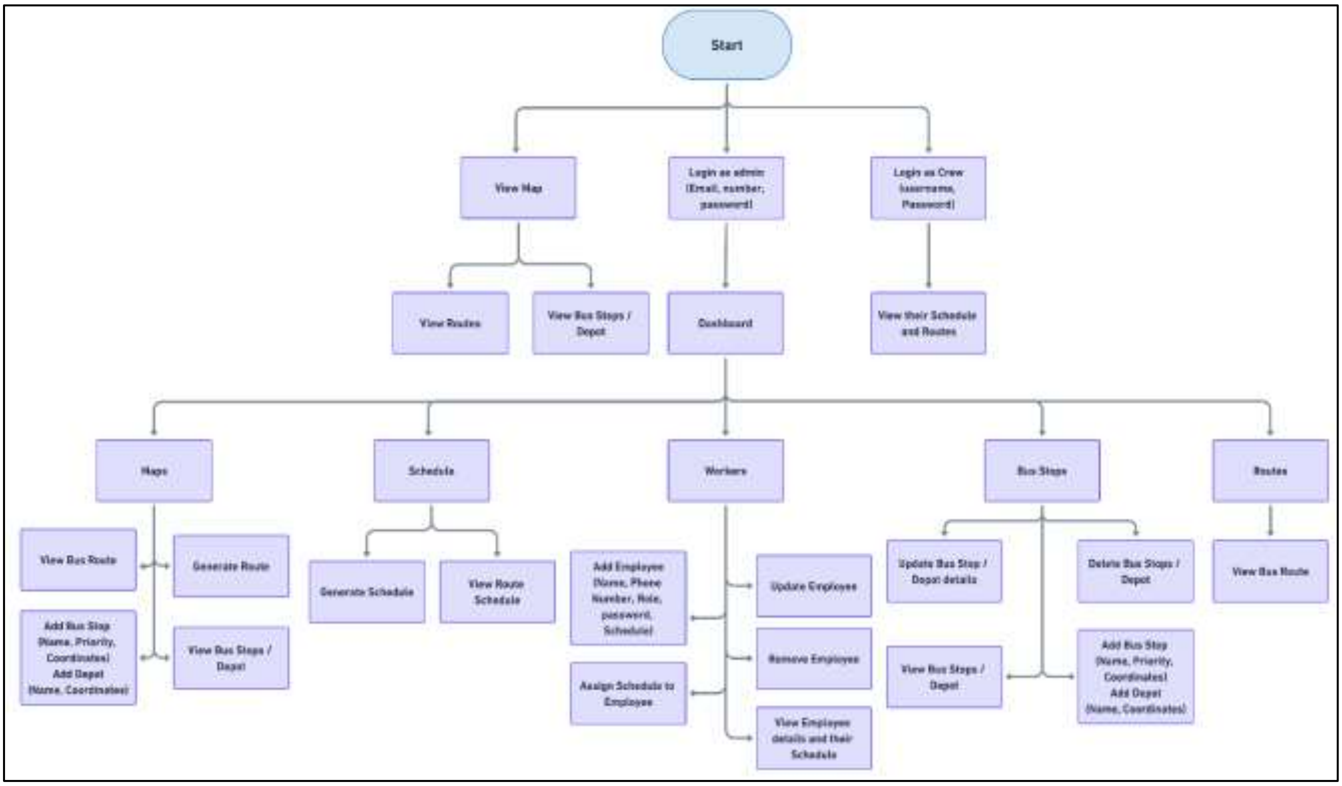

Fig 2. Dataflow

The data flow throughout the system adheres to a logical sequence:

1. Data Acquisition: Information regarding bus stops and depots is gathered through the administrative interface.
2. Preprocessing: Stops are evaluated and clustered according to geographical proximity and operational needs.[1]
3. Route Generation: The LKH algorithm processes clustered stops to create optimized routes, minimizing distance while maximizing coverage.
4. Schedule Creation: Routes are assessed against historical demand patterns to establish frequency and timing requirements.
5. Visualization: Created routes and schedules are displayed on interactive maps via the Leaflet integration.

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C. LKH Implementation for Route Optimization

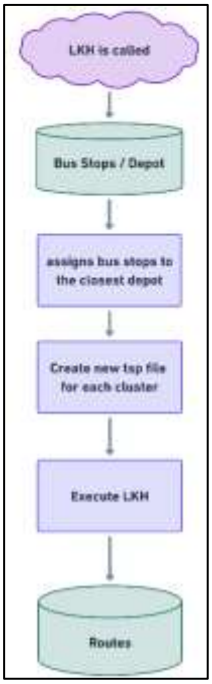

Fig 3. LKH Implementation

The Lin-Kernighan-Helsgaun algorithm functions as the primary engine for route optimization. Our implementation encompasses several transportation-related enhancements:

1. Bus Stop Clustering: Before route optimization, stops are grouped based on geographical closeness, demand patterns, and operational limitations.
2. Multi-Depot Support: The system supports multiple depot locations, computing optimal routes from each.
3. Time-Window Constraints: Route computations include specific time frames for service delivery at every stop.

D. Advanced Crew Scheduling Algorithm

Our crew management scheduling algorithm tackles the intricate challenge through a sophisticated multi-objective optimization method. The algorithm functions in a series of phases:

1. Route Characterization

Each route is defined by several essential characteristics:

- Route ID: Distinct identifier for the route
- Route Length: Physical distance of the route
- Average Priority: Numerical priority value (1-10) that dictates service frequency

2. Schedule Generation

The schedule generation phase formulates a master timetable of all route departures throughout the operating day:

- Beginning from the initial operational hour (06:00), the algorithm cycles through time slots
- Time intervals are adjusted during peak hours to enhance service frequency [2]
- For each route, departure times are arranged according to the route's computed frequency
- During peak hours, the algorithm applies a reduction factor (0. 7) to the regular frequency to amplify service

3. Multi-Pass Employee Assignment

The crew assignment procedure employs a sophisticated multi-pass method with varying optimization strategies:

Assignment Strategies:

1. Time-Based Sorting: Routes are designated in chronological order
2. Priority-Based Sorting: Higher priority routes are assigned initially
3. Distribution-Based Sorting: Routes with fewer departures are given preference

First Pass Assignment

- Attempts various assignment strategies to achieve complete coverage
- Employees are monitored based on availability times and total work minutes
- Assignment choices consider workload balance and route variety
- A scoring system accentuates employees with less work time and route diversity

Second Pass Assignment

- For any unassigned departures, constraints are loosened
- Employees with the least work time are given precedence
- Schedule conflicts remain strictly avoided

4. Schedule Balancing

The final phase guarantees balanced workloads and equitable distribution:

- Route variety is monitored and balanced among employees
- Total work time is tracked to avert overloading
- Morning and evening shift requirements are managed distinctly
- Schedules are organized chronologically for each employee
- The algorithm considers necessary breaks between route assignments

E. Interactive Mapping Implementation

The mapping subsystem utilizes Leaflet's features to offer:

1. Real-time Visualization: Routes and schedules are visually represented in real-time, mirroring the active operational state.
2. Interactive Editing: Administrators can adjust routes and stops directly via the map interface.
3. Layered Information Display: Various data layers (stops, routes, traffic situations) can be switched on and off for thorough situational awareness.
4. Responsive Design: The interface modifies itself to accommodate different device sizes, facilitating both desktop management and mobile field activities.

RESULTS

User Interface

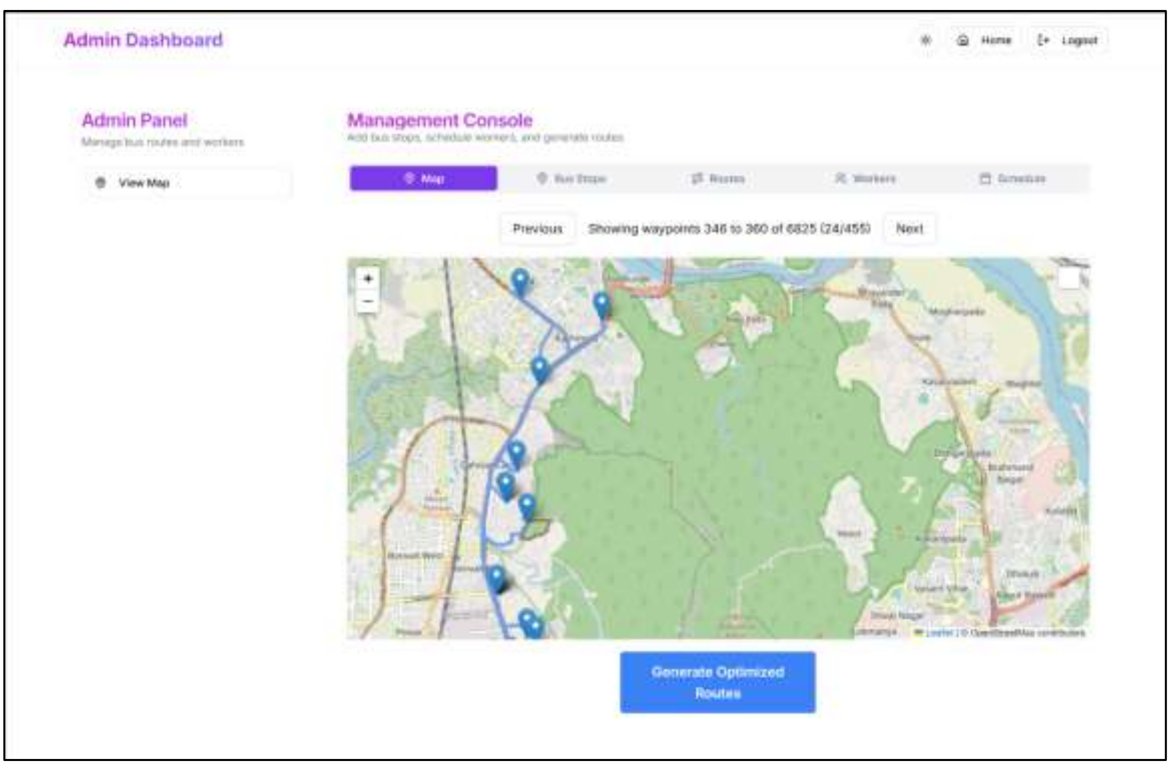

Fig 4. Route Map Display

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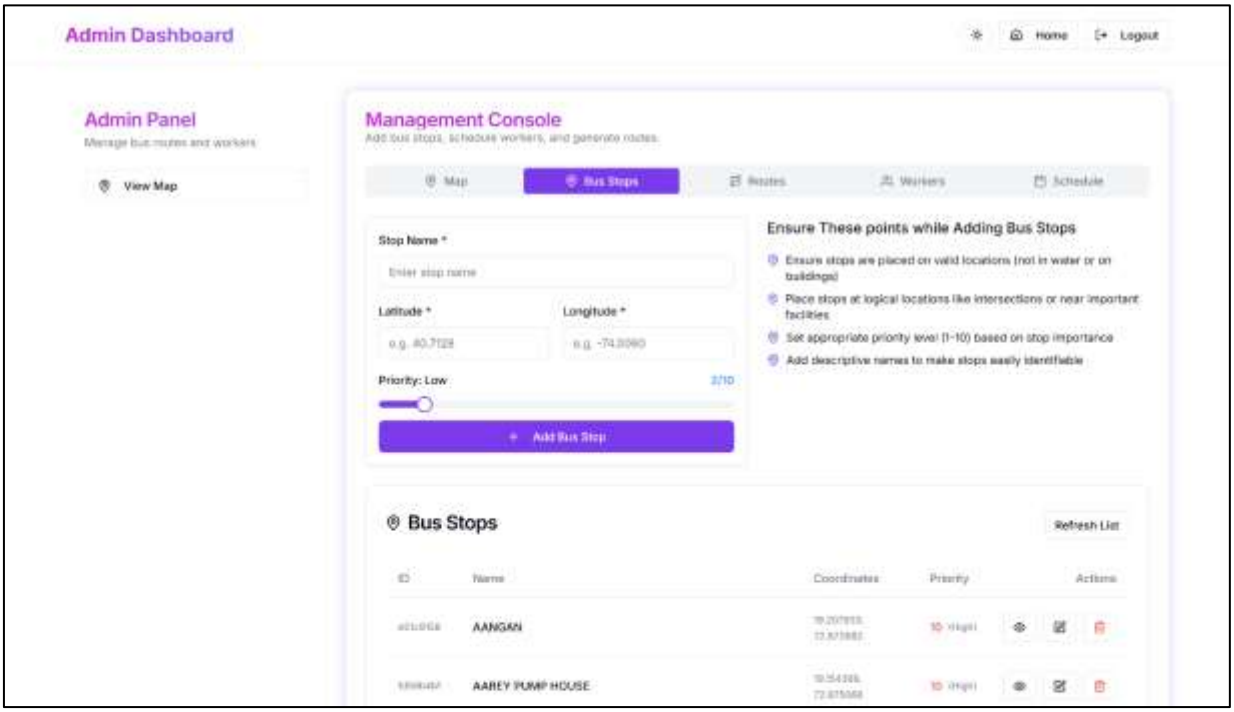

Fig 5. Bus Stop Assignment / Display

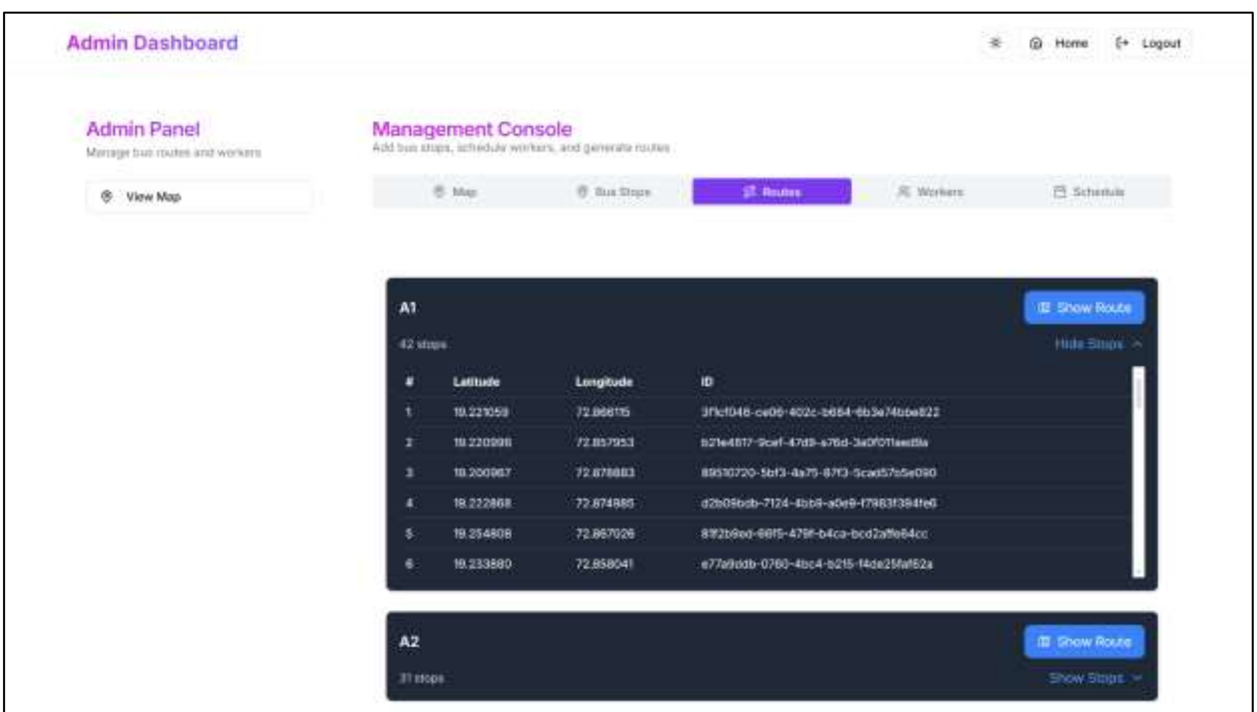

Fig 6. Route Table Display

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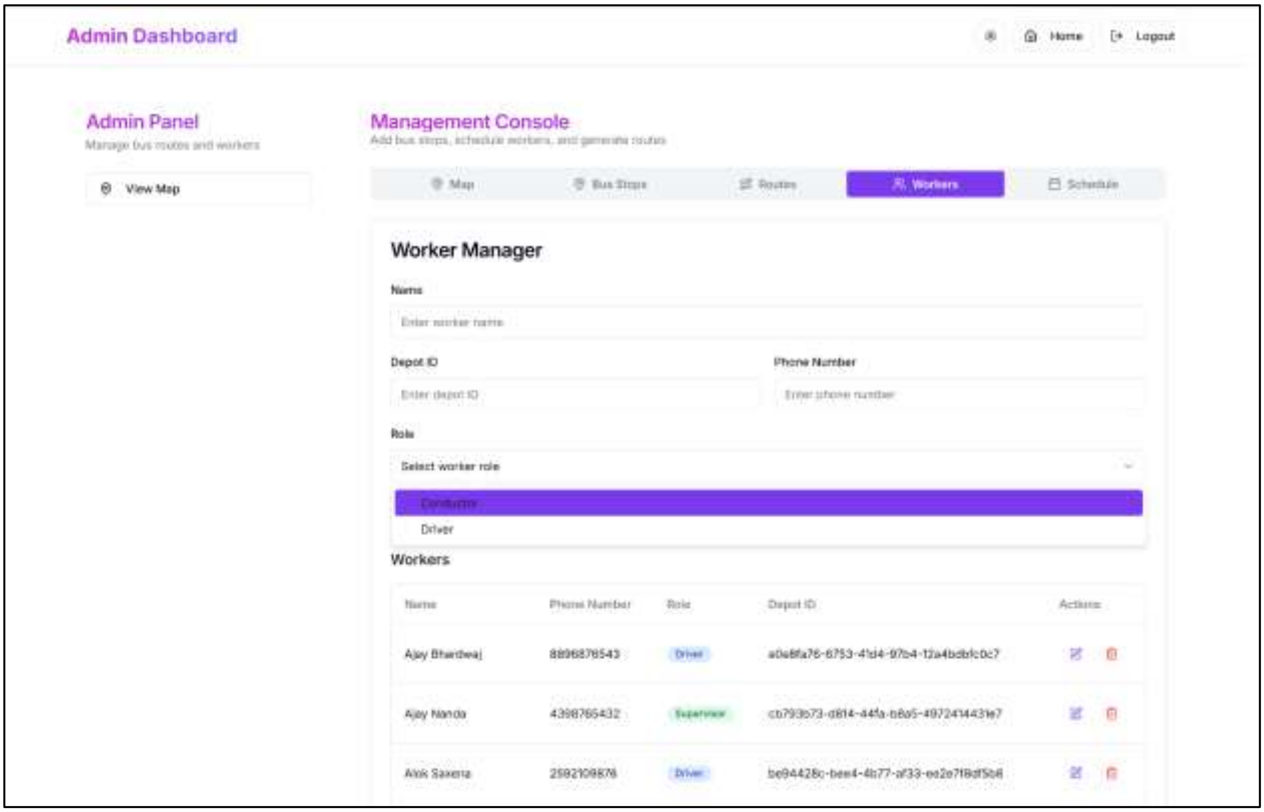

Fig 7. Worker Assignment / Display

CONCLUSION

The Automated Bus Scheduling and Route Management System marks a major step forward in public transit operations. Container microservices help the system to have outstanding scalability, resiliency, and maintainability by supporting continuous updates. Paired with the multi-object crew scheduling approach, the advanced route optimization realized with the improved Lin-Kernighan-Helsgaun algorithm produces tangible increases in operational productivity.

Working to solve the fundamental issues of present transit management, this approach let's

- Creating routes that minimize length and maximize coverage
- Building balanced, effective crew schedules respecting workplace policy
- Real-time visual mappings thanks to interactive maps
- Support of many depots and time window constraints
- Enabling flexible deployment with cloud infrastructure

The system's modular architecture allows it to satisfy upcoming transportation needs without interfering with operational stability. This approach provides a technical basis that brings instant advantages and positions companies for further creativity in public transportation management as transit authorities are under growing pressure to raise service quality and keep costs under control.

FUTURE SCOPE

Situational agility in real time:

- Dynamic Route Adjustment: Using traffic API integrations, apply real-time route adjustments depending on traffic conditions, road closures, or unforeseen events
- Develop features for on-demand routing that changes according actual passenger demands based on opinion transit.
- Use machine learning models along with historical data, events, and weather to estimate customer changes grounded on predictive analytics.

Extended System Features:

- Passenger Mobile Application: Offer passengers a companion app featuring real-time bus tracking, projected arrival times, and fare payment options.
- Connect the system with digital ticketing and payment alternatives: automated ticket integration.
- For route plans and vehicle usage trends, introduce predictive maintenance scheduling based on route assignments

Further Optimization

- Use machine learning technologies that constantly refine routing and scheduling in light of performance data.

- To cut emissions, route optimization should take environmental impact assessments into account.
- For electric bus scheduling that takes into account charging needs and range constraints, include bespoke algorithms.

Advanced Data Analysis

- Create sophisticated reporting software for performance indicators, operational metrics, and cost analysis on the Business Intelligence Dashboard.
- Implement systems tracking passenger load, on-time performance, and other service quality indicators
- Analysis of Passenger Behavior: Study passenger flow patterns to more closely coordinate service with real usage patterns

Integration of Infrastructure

- Integrate smart city: link with urban planning databases, traffic lights, smart intersections, and other city systems.
- Integrate bus-mounted sensor data with the rest of your network for better operational awareness and passenger counting.
- Develop a digital twin of the whole transit system to be used for planning and simulation purposes.

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